MASTER'S THESIS

Fragmentation and Consolidation of Order Books

Majtyka, Jaroslaw

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Fragmentation and Consolidation of Order Books

The market quality implications of MiFID induced fragmentation and consolidation in both displayed and non-displayed order books

Jaroslaw Majtyka
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Bond University School of Business (Finance)

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Abstract

Since the implementation of MiFID on November 1 2007 European financial markets have experienced fragmentation in displayed (lit) order books as well as an increase in the use of non-displayed (dark) liquidity. We empirically analyze the effects such events have on market quality. We find that increased competition for orders resulting from the fragmentation of the displayed liquidity market improves market quality in the form of tighter bid/ask spreads and lower transaction costs, with institutional investors realizing greater benefits than retail investors. Fragmentation between lit and dark order books has a negative impact on market quality as informative trades migrate from lit to dark order book markets leading to greater information asymmetry among market participants. This results in wider bid/ask spreads and greater price impacts as investor confidence in advertised prices decreases and depth moves further from the midpoint of the best bid/ask spread. Increased dark order book fragmentation negatively effects market quality in the form of wider quoted spreads, however the magnitude of the affect is minimal. We also find that while the number of dark trading venues increases over time, the number of unique order dark books, which take into consideration liquidity sharing, remains fairly constant. This indicates that markets can effectively regulate the number of viable dark trading venues.

Declaration

This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Master of Philosophy. This thesis represents my own original work towards this research degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made.

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Table of Contents

Tables and Figures

Tables

Figures

1.0 Introduction

In recent years investors have significantly changed the way they access liquidity. Traditionally, in limit order markets, investors would rely on a single quote driven exchange in which they can observe the advertised prices for a particular stock as well as the quantity available for sale or purchase at each price level. Today, however, investors are increasingly accessing multiple trading venues simultaneously through Smart Order Routing Technology (SORT) and utilizing liquidity that offers no pre-trade transparency, often referred to as non-displayed or 'dark' liquidity. Dark liquidity is sourced from dedicated dark liquidity providers, often referred to as 'dark pools', and can also be found on 'lit' exchanges through the use of hidden orders. This results in an increase in the number of orders that are systematically matched in a black box using liquidity that is hidden from investors. As of July 2013, 14.4% and 33% of total trading activity in the US and Europe, respectively, is taking place in the 'dark', whereas prior to 2000 the proportion remained negligible.[1]

The shift in trading characteristics stems from recent regulatory changes, predominately the introduction of the Regulation National Market System (RegNMS) in the United States and the Market in Financial Instruments Directive (MiFID) in Europe, whose policies encourage the formation of alternative trading venues such as Alternative Trading Systems (ATS) and Multilateral Trading Facilities (MTF) in the US and Europe, respectively.[2] These changes have resulted in the formation of several alternative sources for both lit and dark liquidity and the fragmentation of the US and European equity markets. However, we find that the number of unique dark order books has remained fairly constant indicating that markets are adept at self-regulating the number of viable dark trading venues.

We investigate these events as the majority of households are directly connected to the securities market. According to Mary Jo White of the Consumer Federation of America over half of the USA's residents report that they own a stock directly or through investment vehicles and this is representative of all developed economies. If financial markets are not fair and safe they will not attract investors and will fail to provide companies with the capital they require.

Our study focuses on the market quality implications of fragmentation and consolidation within, as well as across, lit and dark order books. Results on lit order book fragmentation are consistent with those of comparable studies by Degryse, de Jong, and Van Kervel (2011) and Gresse (2012) in that competition resulting from lit order book fragmentation has a largely positive effect on overall market quality in the form of tighter quoted spreads and lower realised and effective spreads as

[1] Values sourced from Rosenblatt Securities Inc. (http://rblt.com/news_details.aspx?id=226)(US) and the Financial Times (http://thomsonreuters.com/products/financial-risk/01_060/12-mth-dark-pools-and-bcs-emsr-table-chart-to-july-2013.pdf)(Europe).

[2] See Section 2.0 - 'Background on MiFID' for more information on how MiFID helped popularize dark liquidity.

venues compete for liquidity by offering discounts to liquidity suppliers. However, effects are greater in the consolidated global order book compared to the primary exchange, as represented by the London Stock Exchange, implying that institutional investors are able to realise greater benefits than retail investors.

The shift in trading towards dark liquidity providers, previously referred to as fragmentation across order books, is attracting the attention of regulators and policy-makers worldwide. Proponents of dark trading argue that allowing trades to take place in the dark affords major investors the opportunity to avoid being 'front run' by sophisticated algorithms that can detect large orders. While it is still possible for this to happen in dark liquidity environments, many dark liquidity providers are proactively putting in place strict customer exclusivity policies as well as controlling the type of information that can be accessed in order to protect investors from predatory behaviour and maintain the quality of their pool.[3] Opponents of dark liquidity argue that by removing visible liquidity from the market, dark liquidity providers hamper the price discovery process and reduces overall market quality. (Ye, 2010, and Forde and Putnins, 2012)

Existing results on the effects of dark liquidity fragmentation on market quality, as measured by quoted spreads, are mixed. Fong, Madhavan, and Swan (2004) find that increased off-exchange activity does not result in higher bid-ask spreads. In a 2006 study, and later confirmed by the author in 2012, Gresse concludes that increased crossing network activity tightens spreads. However, the majority of findings, including our own, support the idea that increased use of dark liquidity has a negative effect on spreads caused by informative trades leaving the market. Degryse, de Jong, and van Kervel (2011) conclude that higher market shares for dark liquidity are associated with wider quoted spreads, which is consistent with the findings of Nimalendran and Ray (2012), Weaver (2011), Forde and Putnins (2012), and Foley, Malinova, and Park (2012).

Evidence on the effect of increased use of dark liquidity on depth is also mixed. Foucault and Menkveld (2008) empirically test their model and find that increased use of dark liquidity leads to an increase in depth at the best price level. These findings are also consistent with those of Buti, Rindi, and Werner (2011) and Gresse (2012). In contrast, through empirical analysis, Degryse, de Jong, and van Kervel (2011) conclude that, much like in our study, depth is reduced in the lit market while Foley, Malinova, and Park (2012) argue that depth is unaffected.

The extent of fragmentation in the dark order book market is difficult to measure. Figure 1 breaks down the market shares of known dark liquidity providers for July 2013, as reported by Thomson Reuters Market Share Reporter.

[3] For additional information see Mittal (2008) – 'Are you playing in a toxic dark pool?'.

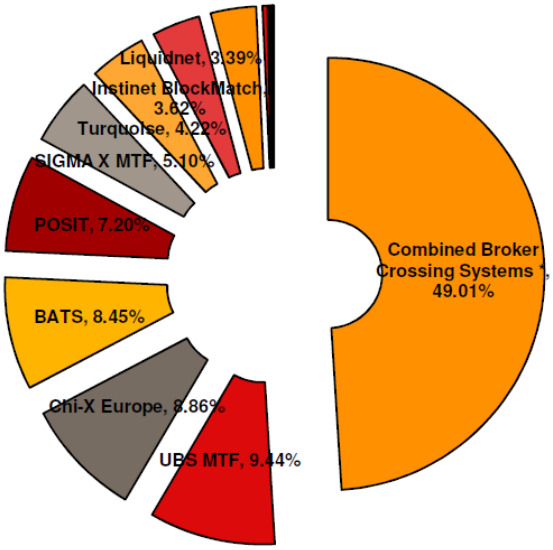

Figure (1) European dark pool market share

The figure presents information on the market shares for various European dark pools for July 2013. *Source:*[*http://thomsonreuters.com/products/financial-risk/01_060/monthly-dark-pools-bcs-emsr-table-chart-july-2013.pdf*](http://thomsonreuters.com/products/financial-risk/01_060/monthly-dark-pools-bcs-emsr-table-chart-july-2013.pdf)

As indicated by the proportion of combined broker crossing system activity in Figure 1, 49% of all reported dark transactions cannot be assigned to a particular trading venue. These trades appear under the Systematic Internalizer (SI) and Over-The-Counter (OTC) flags within the Markit BOAT consolidated trade reporting tape. As a result, previous studies use the overall proportion (market share) of dark trading with respect to total trading volume, both lit and dark, as a proxy for dark trading and/or dark order book fragmentation. Therefore, existing studies examine the market effects that result from the increased use of dark trading but not the level of fragmentation in the dark order book market. Existing studies do not determine whether observed effects result from more dark trading, in terms of volume and market share, or the fact that dark trading is occurring across a wide variety of venues as opposed to a central location. In order to explicitly test for the effects of dark order book fragmentation we assign each dark transaction to the dark liquidity providing venue that facilitated the trade and calculate a fragmentation measure similar to the one used for lit order book markets.

The resulting findings indicate that dark order book fragmentation has a negative impact on market quality in the form of wider spreads and greater price impact. However, the effects are subtle and are more than overshadowed by the effect of lit order book fragmentation and order migration to dark order books.

The remainder of this paper is structured as follows. Section 2 provides an overview of the financial environment including information on major MiFID directives. Section 3 provides a description of dark pools. Section 4 discusses existing literature regarding market fragmentation and the market

quality implications of the increased use of dark liquidity. Section 5 discusses the motivation behind the study and the contributions that this study makes to the fields of market fragmentation and dark liquidity. Section 6 outlines the hypotheses of the study. Section 7 discusses the data used in the study while Section 8 details how the data will be used to test the hypotheses. Section 9 discusses the relevant findings of the study. Finally, Section 10 provides a conclusion while Section 11 discusses further areas of research that could benefit from our unique dark fragmentation measure as well as some of the limitations of the study.

2.0 Background on MiFID

The Markets in Financial Instruments Directive (MiFID), officially implemented in Europe in November 2007, [4] is the replacement to the 1993 Investment Services Directive (ISD). The objective of MiFID is to improve the quality of the financial service industry across Europe by establishing a single regulatory framework for the European Economic Area that protects investors as well as creates a level playing field for competing trading venues, both lit and dark. MiFID establishes three major directives in order to achieve this goal.

The first directive is to foster competition by abolishing both the concentration and default rules. The concentration rule requires that retail orders are executed on the regulated market (i.e. traditional visible liquidity provider such as the London Stock Exchange), which limits the formation new markets and prevents the improvement of market conditions through competition. The default rule requires financial intermediaries to execute orders on the primary exchange unless otherwise specified by the customer. Eliminating these rules provides operators of the three newly classified trading venues with the opportunity to fairly compete for order flow. The three new trading venue classifications are as follows:

> *Regulated Markets(RM)* are traditional exchanges that match buyers and sellers through a visible (lit) order book or through dealers. Newly listed companies will continue to designate on which RM they would like to have primary listing. Once listed, alternative trading venues can facilitate trades in these stocks.
>
> *Multilateral Trading Facilities (MTF)* are similar to RMs in matching third party investors but have different regulatory requirements, one of which entails the levels of pre and post-trade transparency to which they must adhere. Dark pools are a special class of MTF that are exempt from pre-trade transparency requirements.

[4] Many trading venues adapted to MiFID regulations prior to November 1 2007, however all venues were required to have transitioned to the new standards by this date.

Systematic Internalizers(SI) allow customers to trade against the inventory of the service provider or with other clients and are typically organized by investment banks.

MiFID's second directive focusses on transparency and aims to guarantee the flow of information in the market. As markets become more fragmented it is vital that investors are provided with the information they need to make investment decisions. Pre-trade transparency rules are established in order to require trading venues to maintain up to date information on their order books and make that information available to the public so that investors can make informed decisions regarding venue selection. However, waivers do exist that allow certain classifications of MTFs, known as dark pools, to be exempt from providing pre-trade information such as quotes. Post-trade transparency, which requires venues to post the results of all executed trades, is mandatory for all trading facilities, including dark liquidity providers. Prior to MiFID, many over-the-counter (OTC) transactions would either go unreported or be reported to the primary exchange. The establishment of post-trade transparency for all trading venues has resulted in the formation of dedicated trade reporting facilities such as Markit BOAT that provide information pertaining to consolidated crossing, OTC, and SI transactions.

The third directive of MiFID is the introduction of the best-execution rule. This predominantly applies to trading venues that do not operate displayed order books (e.g. dark liquidity providers). Venues that cross client trades must execute orders against the best available conditions with respect to price, liquidity and transaction costs, as well as the likelihood and speed of execution. By doing so venues can attract customers as investors are confident that the transaction price reflects true market conditions. It is left up to the venue to decide whether to cross trades at the European Best Bid Offer(EBBO) or the Primary Best Bid Offer(PBBO) price.[5,6]

An update to MiFID, known as MiFID II, gained parliamentary approval in April 2014. Plans include the introduction of a new category of trading venue, Organized Trading Facilities (OTF), which will bring broker crossing networks (BCNs) under the scope of MiFID regulation. It will also include improvements to pre and post-trade transparency and transaction reporting as well as provide improvements to investor protection.

3.0 What are Dark Pools?

Dark pools are trading venues that, unlike traditional exchanges, do not post bid and ask quotes. Therefore, the resulting venues operate without pre-trade transparency. As they are exempt from pre-trade transparency rules, the status of their order books are unknown at any given time. Trades

[5] See Section 3.4.2 for more information on crossing prices.
[6] See Davies (2008) – 'MiFID and the changing competitive landscape' for more information on MiFID policies.

are automatically crossed at pre-determined points in time by a system that maintains complete trader anonymity and at a price determined externally by either the primary exchange or consolidated market. [7] Trades are required to be reported to a designated trade reporting facility within a window of execution, 30 seconds, but are not required to identify the venue from which the trade originated. As a result, a large portion of dark transaction data, roughly 49%,[8] is consolidated, making it difficult to determine trading volumes for some trading venues.

Dark pools are designed to allow investors to transact large orders without affecting the price in the market. The traditional dark pool customer is a passive investment fund that needs to adjust its position. However, in recent years the majority of transactions are small and likely originate from an algorithmic trading system (Nimalendran and Ray, 2012).

3.1 Types of Dark Pools

Degryse, Van Achter and Wuyts (2009) identify three distinguishing features of dark pools. The first is their market model and refers to the way in which orders are executed, including the frequency at which they are crossed (continuous vs. periodic)[9] and the way in which orders are matched (blind vs. advertisement based matching which contains minimum pre-trade transparency in the form of notices of the existence of a counter-party to the trade). The second and third distinguishing features are the ownership structure and clientele base, respectively.

It is argued, through both theoretical and empirical studies, that the diversity in trading structure amongst venues exists to serve the various trading requirements of heterogeneous clientele (Fong, Madhavan, and Swan, 2004, and Gresse, 2006) including preferences in trading speed, order sizes, anonymity, and likelihood of execution. While trading systems exist to serve the needs of heterogeneous clientele, it is believed that systems with similar offerings will eventually consolidate as customers gravitate to what they believe to be the better venue (Pagano, 1989).

Mittal (2008) uses the aforementioned features and classified dark pools into the following five categories:[10]

3.1.1 Public Crossing Network

Public crossing networks are the most traditional of all dark pools. They are the pools to which most buy-side firms connect and typically form when agency-only brokerage firms seek alternative sources of revenues, such as commissions. A key feature of public crossing networks is that client

[7] See Section 7.5.2 for more information on the consolidated market and how it differs from the primary market.
[8] According to the Thomson Reuters Market Share Reporter (http://thomsonreuters.com/products_services/financial/financial_products/a-z/market_share_reports/).
[9] See Section 3.4.1 – 'Matching Frequency' for more information.
[10] For additional information see Mittal (2008) – 'Are you playing in a toxic dark pool?'.

orders do not interact with those of the dark pool operator. Public crossing networks rely on their ability to offer liquidity through a unique model, which can be difficult, and as a result have seen few entrants over recent years.

Public crossing networks generally match orders on a continuous basis (i.e. as orders arrive) without conveying an investor's buy or sell intentions to anyone. However there does exist a subset of firms that match orders based on advertisements. In these advertisement-based pools an alert goes out to the traders informing them of a potential match. Systems vary in the way alerts are sent. In some cases both sides receive an alert for the potential match and neither party is committed to the order. In other cases one side will be committed while the party who receives the alert has the option of whether or not to execute the trade.

Major public crossing networks include POSIT, Instinet, and Liquidnet, which are some of the first entrants into market.[11]

3.1.2 Internalization Pools

Internalization pools are designed to internalize an operator's trade flow. Their purpose is to save the trading venue money by allowing orders to be crossed internally rather than sent outside to external trading venues and incurring transaction fees. Internalization pools are also operated by buy-side firms as a means of generating additional commissions. The primary difference between internalization pools and public crossing networks is that internalization pools allow for client orders, from both retail and institutional clients, to interact with the proprietary order flow of the operator.

Major internalization pools include Credit Suisse's Crossfinder and Goldman Sachs' Sigma X.

3.1.3 Ping Destinations

Ping destinations are, in some ways, the complete opposite of public crossing networks. Client orders interact exclusively with the owner's propriety order flow as opposed to with each other, making the Ping Destination a new form of market maker. They are also quite unique in the sense that they only accept Immediate or Cancel(IOC) orders, which require interaction with venue owned shares. If only client trades were crossed then the probability of execution would be extremely low due to the unlikelihood of two opposing orders entering the pool at the exact same time.

Ping destinations rely on quantitative models operating in a black box to make decisions as to whether or not to accept an IOC order. The majority of their customers are sell-side firms that use dark pool aggregators or Smart Order Routing Technology (SORT) to locate sources of liquidity.

[11] This supports the previous statement that there have been few new entrants classified as Public Crossing Networks.

3.1.4 Exchange Based Pools

Two sources of dark liquidity are combined in this category as they share many defining characteristics. The first are dark pools that are registered as MTFs by the operating exchange and include Turquoise Dark and Xetra Midpoint. The second are implicitly created pools formed as the result of the introduction of hidden order types on the operating exchange. Hidden orders differ from iceberg or reserve orders in that not even a portion of the order is made visible on the lit exchange, thus preventing any changes to displayed quotes.

3.1.5 Consortium Pools

Consortium pools differ from the aforementioned venue classifications in that they are established by a group of partnering brokers. They are similar to public crossing networks except they are not typically run by agency-only firms. They also resemble internalization pools except they are established as separate organization, and as such fall under regulatory guidelines that require for increased transparency in their activities.

3.2 Are They New?

While the dark pool as a distinct venue may be a new phenomenon the concept of 'dark' or 'hidden' liquidity is not new. Reserve/Iceberg orders predate dark pools and allow investors to submit large volume orders to the market in increments while publicly displaying only a specified portion of the total order size. Reserve/Iceberg orders, however, are not entirely hidden because a portion of the order is still made public. Hidden order types are also a historical transaction type that allow for dark liquidity within a lit order book. Other forms of dark liquidity include floor broker orders and specialist capital on floor-based exchanges, working orders handled by agency brokers or broker-dealers, dealer capital and stand-alone as well as broker and exchange/ECN operated crossing networks (Buti, Rindi, and Werner, 2011).

Dark pools as a separate entity are also a decades old phenomenon. However, it is only recently that they have been absorbing a significant market share of order flow, thus gaining attention on a global scale (Degryse, van Achter, and Wuyts, 2009). Crossing networks originate from the early 1970s and consist of phone based networks between buy-side traders. Though we must note that the liquidity being provided is not completely dark as the broker requires knowledge of the transaction in order to find a counter-party. Nevertheless, since the intentions of the parties are not made public until after the trade is completed, they, like upstairs market transactions, are still considered a source of dark liquidity. In the 1980s electronic networks such as Instinet and POSIT were introduced which eliminated the need for human interactions and thus improved the anonymity of crossing network transactions.

There are currently over 40 dark pools operating separately in both the US and in Europe with consolidated market shares of 14.4% and 33%, respectively.[12] Their recent growth is attributed to the introduction of new regulations, such as RegNMS in the US and MiFID in Europe, that result in an environment that is more conducive to the formation and expansion of alternative trading venues. Growth in the popularity of dark liquidity is also attributed to improvements in technology, such as algorithmic order routing, which directs order flow to various trading venues while protecting investors' interests by taking into account prices, liquidity, and market impact, among other variables. (Degryse, van Achter, and Wuyts, 2009)

3.3 Vs. The Upstairs Market

The upstairs market refers to when trading occurs within a broker-dealer firm as opposed to a traditional exchange. Upstairs market trades, like those originating from dark pools, are protected under regulatory policy and subject to the best-execution rule. This rule stipulates that prices given to customers must not be less favourable than those offered to investors by visible order book operators. As a result, the best-execution rule states that prices must fall within best bid and ask spread of the primary or consolidated market. [13]

The main difference between the two trading venues is that dark pools operate using an electronic trading system which requires no broker or dealer involvement, resulting in complete pre-trade transparency. Since dealers in the upstairs market contact other dealers in order to source liquidity there is potential for some information leakage. In his paper 'Do Dark Pools Harm Price Discovery?' Zhu (2012) acknowledged that although this type of liquidity is not usually classified as dark, it is still a source of non-displayed liquidity. Another difference between dark pools and the upstairs market is said to be the trading cost, which is theoretically lower in dark pools (Lefebvre, 2010).[14]

3.4 How are Transactions Executed?

The following illustrates the steps involved in completing a transaction within a dark pool: [15]

i. The trader who would like to buy/sell the security calls his broker or places an order over the electronic system of the broker.
ii. The broker internalizes the order and looks for suitable matches within his network. This work is sometimes done by computer algorithms which can break the order up into several pieces and locate the most appropriate venues for executing the transactions.

[12] Values sourced from Rosenblatt Securities Inc.(http://rblt.com/news_details.aspx?id=217)(US) and the Financial Times (http://www.ft.com/cms/s/0/f1142a76-322a-11e2-b891-00144feabdc0.html#axzz2L7xhct7b)(Europe).
[13] See Section 7.5.1 for more information on the distinction between primary and consolidated markets.
[14] See Section 4.1 – 'General Market Fragmentation Literature'.
[15] Steps sourced from Achuthakumar(2009) - 'Dark pools of liquidity'.

iii. The transaction details are forwarded to clearing and settlement houses.

iv. The confirmation of the trade and trade details are then provided to the two parties.

3.4.1 Matching Frequency

Dark pool orders can be matched in the following ways:

Continuous cross: Orders are matched as they enter the system.

Periodic cross: Orders are processed in batches at pre-determined times throughout the day. These are among the first types of dark pools. Over time companies began offering more frequent crossing opportunities until they finally began offering continuous crossing. Posit Match is an example of an existing periodic crossing pool.

Advertisement based: Alerts are provided to one or both parties of the transaction. Systems vary in the way alerts are sent. In some cases both sides receive an alert for the potential match and neither party is committed to the order. In other cases one side will be committed and the party who receives the alert has the option of whether or not to execute the trade.

3.4.2 Price Determination

Regulatory policy, specifically the best-execution rule, dictates that transactions in a dark pool environment cannot be executed at a price that is less favourable than that offered to customers of traditional exchanges. As such, transactions are executed at a price referencing one of the following:

National Best Bid and Offer (NBBO)(US) - The best bid and ask prices as determined by the consolidated national market.

Primary Best Bid and Offer (PBBO) - The best bid and ask prices as determined by the exchange of primary listing.

European Best Bid and Offer (EBBO) – The best bid and ask prices as determined by the consolidated European market.

While the NBBO is the standard in the US, European dark pool operators have the option of referencing either the PBBO or EBBO. Originally most operators referenced the PBBO however recent trends have shown that there has been a preference to switch to the EBBO.[16]

[16] See 'Instinet first to float EBBO' (http://www.thetradenews.com/newsarticle.aspx?id=8293).

Though all pools allow for trades to be executed at the midpoint, some venues also allow transactions at the best bid or best ask. The benefit from executing at the best bid/ask is increased probability of execution by moving towards a price for which an outstanding limit order may exist (e.g. There are no orders at the midpoint but plenty of limit orders exist to sell to you at the higher ask price/buy from you at the lower bid). In order to further cater towards the heterogeneous needs of investors some pools have also allowed for more specific transaction pricing. For example, a trader who wishes to purchase stock but does not place significant value on immediacy can specify 'midpoint-1 cent'. On the other hand, a trader who values immediacy can place an order at 'midpoint+1 cent' and increase the probability and speed of finding a match. In most cases investors can also specify a limit price in order increase the probability of execution (Ray, 2010).

Prices are generally decided upon after a match has been made. An order enters a dark pool and either immediately or after some time finds a counter-party to the trade. At that point the electronic system references the designated BBO and decides upon a price for the transaction. There are some instances in which prices are determined before the match has been made. Instinet, for example, operates a closing cross that matches orders at the closing price. However, in order to prevent predatory trading, it closes crosses for any company that makes an announcement after markets have already closed (Ye, 2010).

3.4.3 Types of Orders

Dark pools allow for the use of the following order types:

Market order – The order is filled in reference to the prevailing BBO.

Limit order – The order is filled at a price no worse than the customer specified limit in reference to the prevailing BBO.

Immediate or Cancel (IOC): The order is either filled in its entirety, in reference to the prevailing BBO, or removed from the liquidity pool. Many dark pools no longer allow this feature as it can be used for gaming purposes to try and detect available liquidity.

3.4.4 Order Attributes

The following is a list of key trade attributes that modify the order type:

Mid-Point: The order is pegged to the prevailing mid-price of the NBBO/EBBO/PBBO quote.

Pegged order: The order is pegged to any point inside the spread (e.g. bid, ask).

Minimum Quantity: The order cannot interact with orders smaller than this quantity for the first fill.

Persistent minimum quantity: The minimum quantity is forced throughout the life of the order and not just for the first fill.

Limit Price: Do not execute the order at a price inferior than the limit price.

Do not interact with: Exclude various counter parties including other dark pools or liquidity partners.

Send/Do not send IOI: Refrain from sending Indication of Interest messages to other dark pools or liquidity partners. These messages are used to find available liquidity from external sources. They do not often include information about the size of the order or whether the party is a buyer or seller. Many dark pools no longer allow this feature as it can be used for gaming purposes to try and fish out available liquidity.

3.4.5 How is Liquidity Accessed?

Orders sent to a dark pool first interact with the resident dark order book. If the necessary liquidity is not available they are then sent to either the proprietary lit order book, in the case of exchange based pools, or to the dark order books of partnering companies. In order to increase the probability of execution[17] for their clients many dark pool operators have developed liquidity sharing agreements with their competitors. The result is a mutually beneficial relationship which satisfies clients' needs for liquidity while maintaining a steady customer base that would otherwise be lost in the face of high rates of non-execution. Finally if the order is still not filled the remainder is sent to the primary exchange. This type of strategy does require the client to have access to some Smart Order Routing Technology (SORT). [18] As such this is often feasible for institutional investors but not so for retail clients who could not financially justify the investment.

In order to maintain an acceptable likelihood of execution some dark pools have developed liquidity partnerships with competing trading venues, as mentioned above. [19] The result is that if an order cannot be completed on the proprietary dark order book it is immediately sent to the partnering

[17] Probability of execution is found to be lower in a crossing network and has been noted as being one of the largest costs associated with dark liquidity trading (Ye, 2011).
[18] The increase in use of SORT technology(Hendershott and Riordan, 2009) in aggregating dark liquidity has resulted in participation rates of 15-25% (Altunata, Rakhlin, and Waelbroeck, 2010).
[19] See article 'Instinet Europe joins TQLens' (http://www.tradeturquoise.com/press/instinet_europe_joins_tq_lens.pdf).

order book. A key benefit of this is improved probability of execution for retail clients who do not have access to SORT. It has been estimated that up to 99% of a crossing network's transactions are crossed against clients' transactions from an external dark pool (Nimalendran and Ray, 2012).

It should be noted, however, that investors often have the option to refrain from sending their orders to particular venues, including primary lit exchanges. The main reason for this is that some investors may want to refrain from transacting in what are known as 'toxic' pools.[20] Toxic pools are those that do not restrict the type of activity that occurs in the pool and, as a result, subject clients to predatory behaviour.

3.4.6 Trade Reporting

In accordance with the post-trade transparency regulations of MiFID, trades must be reported within 30 seconds to a designated trade reporting facility (TRF), such as Markit BOAT, once the transaction has been finalised (Nimalendran and Ray, 2012). Dark pools have the option of allowing their identity to be known when reporting the transaction. If a pool chooses to refrain from reporting their identity the transaction will be flagged as either OTC or SI in the TRF's consolidated tape.

If a large order is executed in pieces the individual trades must be reported as they occur. Providing a minimum quantity with the order will therefore help prevent those interested in gaming from identifying that there may be a large order in the market as they are not likely to place large orders during 'fishing' expeditions.[21]

Prior to MiFID, trades originating from dark pools would either be reported to a primary exchange, such as the London Stock Exchange, [22] or would not be reported publically at all. One of MiFID's key directives is to increase the level of transparency in the market and make sure that all trades are reported, though the identities of the reporting firm can continue to remain secret.

Unfortunately, allowing trade reporting firms to refrain from having their firm specified as the source of the transaction has introduced a degree of difficulty into academic research on dark pools. This inability to locate the source of the transaction has made it difficult to measure just how fragmented the market has become since the rise in the popularity of dark liquidity. While total dark volume can be measured it cannot be done on a trading venue by trading venue basis. According to Thomson Reuters Market Share Reporter, roughly 49% of the total dark trading activity in Europe cannot be traced to an originating venue.[23]

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[20] For additional information see Mittal(2008) – 'Are you playing in a toxic dark pool?'.
[21] See Section 3.6 – 'Drawbacks of Dark Pools' for more information on gaming.
[22] See 'Liquidnet Europe signs up with Markit BOAT' (http://www.securitiestechnologymonitor.com/issues/19_61/22379-1.html).
[23] See link for more details (http://thomsonreuters.com/products_services/financial/financial_products/a-z/market_share_reports/).

3.5 Benefits of Dark Pools

The option to avoid displaying an order to a continuous limit order book offers several advantages. One of the key advantages is the ability to prevent your order from being imitated by those in the market. If others were to gain knowledge of your intentions and put forth similar trades they can reduce the alpha of your investment strategy. Displayed orders also leave themselves open to being front-run. Front-running occurs when another investor manages to place an order with higher priority on the same exchange and, as a result, moves the price in an unfavourable direction. This increases the cost of your transaction and lowers your future returns (Buti, Rindi, and Werner, 2011).

Orders are also only reported if a transaction is successful, thereby maintaining your intentions private and allowing you to make another attempt at transacting without informing other investors. This proves to be particularly helpful for transactions in low volume (turnover) and small-cap stocks as the intention to transact can hold more informative value for these stocks compared to high volume and high-cap stocks.

Another, more obvious, reason for the use of dark pools is that participants no longer pay the bid-ask spread to transact. Each party is responsible for half the spread as orders are often executed at the midpoint; an exception is made for orders transacted at the best bid or ask but those are likely done for more strategic reasons such as improving the probability of execution while maintaining anonymity. While executing a trade at the midpoint can be replicated in the lit market by posting a quote at the midpoint, doing so causes you lose the benefits of anonymity.

Investors who place orders with a traditional broker are subject to significant commission fees. Dark pools are often associated with lower transaction fees.[24]

Dark pool trades also allow for minimal price impact. [25] Large orders executed in a visible order book can exhaust several levels of bid or ask prices and can, therefore, widen the spread significantly, depending on the depth of the order book and the volume being traded.

Unfortunately some argue that almost all the potential savings gained from accessing dark liquidity are lost to adverse selection (Altunata, Rahklin, and Waelbroeck, 2010).

3.6 Drawback of Dark Pools

There are two main disadvantages to the use of dark pools. Firstly, there is a potential lack of immediate executions, due to insufficient liquidity, as there is no guarantee that there is an opposing order sitting within the liquidity pool. As a result, some orders sit in a dark pool for a significant

[24] As noted in the Pricewaterhouse Coopers report by Caplan et. al. – 'Dark pools of Liquidity' (http://www.pwc.com/us/en/alternative-investment/assets/NY-10-0105-PwC-alt-Caplan.pdf).
[25] See Section 4.1 – 'General Market Fragmentation Literature'.

amount of time, during which prices move unfavourably, resulting in increased transaction costs. This is even more evident in periodic crossing pools as orders may not be processed for several minutes after submission, thereby increasing the wait time needed to verify the status of the transaction. Lack of liquidity in the pool resulting in partial execution is also a problem as the reporting of partial order execution can reveal your intentions to the market, thereby potentially negating further benefits from anonymity. Conrad, Johnson, and Wahal (2003) and Ready (2013) ask why dark pools, with all of their benefits, are not more popular and conclude that it is largely due to the low probability of execution.

Secondly, there is a potential for gaming in dark pools. As information about orders is not posted until after the transaction has been executed it is important to ensure there are no information leakages with regards to the size and direction of a particular order. If information is leaked, competing investors have the opportunity to enter the regular market and trade in the same direction as the pending dark order, thus moving the price in an unfavourable direction. This type of information leakage is accomplished through what is known as fishing – sending a series of small orders in order to try and detect whether a large order exists in the dark pool. Regulators are concerned that this type of activity, in addition to the use of advertisement based pools, can result in information asymmetry in the market whereby some investors have key information that is not available to the general market. The result is likely to be inhibited growth a crossing network's activity (Ray, 2010).

Many pools, however, attempt to limit the prospect of gaming by imposing rules such as minimum order sizes and minimum resting periods for orders (i.e. orders cannot be cancelled within a certain amount of time), as well as not allowing IOC order types or the sending of IOIs.[26] They also attempt to restrict access to their pool. For example, some dark pools do not allow high frequency traders in order to maintain a certain quality of trades.

4.0 Literature on Market Fragmentation and Dark Liquidity

This section focuses on the relevant literature on market fragmentation in both lit and dark environments.

4.1 General Market Fragmentation Literature

Theoretical and empirical work on the benefits of market consolidation and fragmentation results in mixed findings. The following outlines they key points to both sides of the argument.

[26] See Section 3.4.3 for information on types of dark orders

4.1.1 Benefits of Consolidation

Mendelson (1987) argues that finding a counterparty is easier when markets consist of more investors willing to trade. Therefore, a market becomes more attractive as the number of traders increases. In similar fashion, Pagano (1989) concludes that in the light of two similar market choices, investors concentrate in the market where the number of traders is foreseen to be greater. The reason behind both authors' conclusions is that either investors are attracted to the idea of increased probability of execution resulting from a larger pool of investors or that the costs of transacting in the more consolidated market is decreased due to its ability to utilize economies of scale in minimizing the fixed cost per trade paid by market participants.

Increases to the number of markets listing assets can lead to an increase in adverse selection costs (Chowdry and Nanda, 1991, and Forde and Putnins, 2012). It also provides dealers and market makers with the opportunity to cream-skim profitable orders which negatively effects liquidity in the form of wider bid-ask spreads and results in increased volatility (Madhavan, 1995, Easley, Kiefer, and O'Hara, 1996, Bessembinder and Kaufman, 1997, and Zhu, 2012).

Bennet and Wei(2006) study the market quality implications of migrating a primary listing from a fragmented market (NASDAQ) to a consolidated market (NYSE). The NASDAQ is classified as fragmented as it is a dealer market where trades are executed by a large number of trading venues such as Electronic Communication Networks (ECNs), dealers, and regional exchanges. On the other hand, the NYSE is a more traditional exchange with order flow directed to a single trading venue. They examine 39 stocks that transfer listing from 2002 to 2003 and find that switching results in an improvement in liquidity provisions and price efficiency. They also observe additional improvements in market quality in the form of reduced volatility as well as quoted, effective, and realised spreads, which is confirmed in a later study by Gajewski and Gresse (2007).

Foucault and Menkveld (2008) investigate the effects of the launch of EuroSets, operated by the London Stock Exchange (LSE), into the Dutch stock market alongside the already established EuroNext exchange. They question whether the introduction of a new market improves liquidity and whether protection against violation in price priority for limit orders is necessary. They conclude that the consolidated, or global, limit order book is deepened after the introduction of EuroSets. However, higher trade-through rates in the entrant market imply that protecting lit orders against trade throughs would be important in preserving the quality of transactions.

In contrast with the findings from Foucault and Menkveld (2008), Riordan, Storkenmaier, and Wagener (2010) find that investors execute trades at the best price level in spite of a lack of price protection. They investigate the fragmentation of lit exchange markets on UK stocks resulting from the introduction of three new lit MTFs: Chi-X, BATS, and Turquoise. The authors find that price

protection was not necessary as investors made it a priority to stay informed and protect themselves by monitoring multiple markets; price competition was obviously important to them. However, as not all investors can afford such monitoring techniques, some investors will still be subjected to increased trade-through rates and will require some sort of investor protection.

4.1.2 Benefits of Fragmentation

Proponents of market fragmentation argue that it has positive market effects and increases investor welfare when introduced. Monopolistic trading environments often result in non-competitive behaviour and the introduction of a competitor aids in improving trading costs in the form of tighter bid-ask spreads as increased competition forces liquidity suppliers to improve their prices. (Fong, Madhavan, and Swan, 2004, and Foucault and Menkveld, 2008). Hendershott and Mendelson (2002) and Gresse (2006) find that markets fragment to serve the different types of trading requirements of different classes of investors. They also confirm that the ability to serve different classes of clientele is a clear benefit of fragmentation.

However, some authors believe that fragmentation is beneficial to the market only up to a certain point. Degryse, de Jong, and van Kervel (2011) find that visible fragmentation has an inverted U-Shape showing that the marginal benefit of fragmentation decreases over time, resulting in an ideal level of fragmentation of 32% as measured by 1- the Herfindahl-Hirschman Index.[27] They find that fragmentation improves liquidity about the midpoint but has a lesser effect deeper in the visible order book. The authors also argue that the nature of fragmentation is an important factor, with visible fragmentation having a positive effect on global liquidity while the effect resulting from dark order fragmentation is negative.

4.2 Dark Liquidity and Price Discovery

Dark pools have come under scrutiny with regards to the role they place in the price discovery process. In May 2009, James Brigagliano of the Securities Exchange Commission(SEC) said that dark pool could impair the price discovery process by drawing valuable order flow away from the public quoting market. He also added that anything that significantly detracts from the incentive to display liquidity in the public market could decrease that liquidity and in turn harm price discovery and lead to increased short term volatility.[28] The remainder of this section focuses on the theoretical and empirical studies on the effect that dark liquidity has on the price discovery process.

4.2.1 Theoretical

Theoretical work on the effect of dark liquidity on the price discovery process shows that academics have significantly differing opinions. A 2002 study by Hendershott and Mendelson analyses the

[27] See Section 8.2.1 for more information on the index as it is incorporated in our study.
[28] See 'SEC's Brogagliano on the need for Market Structure' (http://mutualfunddirectorsforum.blogspot.com.au/2009/05/secs-brigagliano-on-need-for-market.html).

interaction between dealer networks and a relatively new form of trading venue, passive crossing networks. The study finds that investors who use the dealer market as a last resort can induce dealers to widen spreads. Traders who only use crossing networks, however, can provide a counterbalancing effect by reducing adverse selection by attracting new liquidity and providing an alternative to the dealer market for informed investors.

Ye (2010) develops a theoretical model determining the market outcome when informed traders have the option of sending their trades to either a displayed limit order book, operated by a traditional exchange, or a crossing network, a particular type of dark pool. The result is that routing orders to a crossing network reduces price discovery, with the impact being higher for stocks with higher fundamental value uncertainty. Ye also concludes that the use of a crossing network harms price discovery if informed traders are able to trade in the crossing network. The intuition behind this model is that investors move their trades between crossing networks and stock exchanges until they are indifferent between non-execution probability in the crossing networks and price impact in the traditional exchange (Ye, 2011).

Zhu (2012) develops a similar model but, unlike Ye (2010) who assumes exogenous choices of trading venues by liquidity traders, Zhu assumes endogenous venue choices by liquidity traders, which is critical to the resulting findings. The study improves on other models that exogenously fix the strategies of informed traders. Hendershott and Mendelson (2002) do not consider the role asymmetric information plays regarding to the value of the asset (Degryse, Van Achter, and Wuyts, 2009, and Buti, Rindi, and Werner, 2010). The result is that informed investors cluster on the heavy side of the market, thereby facing low execution probability in the dark pool, relative to uninformed traders, as there orders are positively correlated with the value of the asset, and therefore each other. This results in traditional exchanges being more attractive to informed investors, improving the price discovery process by concentrating price-relevant information on the exchange. It also results dark pools being more attractive to uninformed investors as liquidity orders are less likely to correlate with each other, thereby maintaining a higher probability of execution.

4.2.2 Empirical

Forde and Putnins (2012) conduct an empirical analysis regarding the impact of trading without pre-trade transparency on price discovery. They use Australian data from the ASX All Ordinaries index from February 1 2008 to 30 October 2011. Their results are in line with Ye (2010) and reveal that aggregate price discovery is impeded and prices become less efficient as order flow migrates from lit to dark trading venues. The result is a decrease in the incentive to engage in costly information acquisition which causes a further reduction in the informational efficiency of prices. They do not, however, find any evidence that large block trades that occur in the dark impede price discovery.

Nimalendran and Ray (2012) use proprietary crossing network transaction data from June 1 2008 to December 31 2009 to examine the information linkages between dark and lit trading venues. By using transaction level crossing data from an actual crossing network they are able to gain insight into the exact nature of dark pool trades. This, however, also introduces a limitation to the results as they are drawn from a single source. They conclude that, in addition to lit exchanges, crossing networks provide a venue for informed traders to trade strategically and, as a result, facilitate the price discovery process. The extent to which the price discovery process is supported, however, depends on the nature of the trade. While trades in less liquid stocks against members of the crossing networks transmit significant information to the lit exchange, trades in liquid stocks, trades by the crossing network's brokerage desk, and large blocks in negotiated crosses transmit less information.

In contrast to the work by Forde and Putnins (2012) and more in line with the theoretical conclusion of Zhu (2010) and the empirical work of Nimalendran and Ray (2012), Brandes and Domowitz (2010), who study dark pool trading in Europe, find that increased dark trading is beneficial to price discovery. Using 2009 data from US trade reporting facilities, O'Hara and Ye (2011) also find that increased market fragmentation through the use of dark liquidity sources leads to more efficient prices.

4.3 Dark Liquidity and Market Quality

The following sections focus on the various theoretically and empirically driven studies of the relationship between dark liquidity and market quality.

4.3.1 Theoretical

Buti, Rindi, and Werner (2010) develop a theoretical model in which traders can submit their order to either limit order book or a dark pool. They extend the previously available literature by building a model of dynamic limit order markets, whereas previous work is comprised of static models. They conclude that when a dark pool is introduced alongside a limit order book, total welfare, as well as institutional traders' welfare, increases, however only for liquid stocks. The improvements to institutional investors' welfare are consistent with the findings of previous studies such as Conrad, Johnson, and Wahal (2003). Retail traders' welfare, however, is found to always decrease. The authors find that, for liquid stocks, both limit and market orders migrate to the dark pool, resulting in tighter spreads. However, competition for illiquid stocks lowers the probability of execution of limit orders and results in a widening of spreads.

The effect on bid-ask spreads is found to be ambiguous in a study by Hendershott and Mendelson (2002). The authors find that even though the new market may attract new liquidity dealers and

result in lower spreads, the potential for the dealer markets to be used as a market of last resort causes spreads to increase.

In contrast, Zhu (2012) argues that informed traders have low execution probability in dark pools as they often trade on the same side of the transaction. Therefore, they move to traditional markets and, as a result, adversely affect liquidity in that market in the form of wider bid-ask spreads and higher price impact. This is consistent with concept of cream-skimming.

4.3.2 Empirical

In their 2004 study, Fong, Madhavan, and Swan examine the market quality impact of block trades across three trading environments listed in decreasing order of transparency: a visible limit order book, the upstairs market and a crossing network. They find no evidence that competition from the upstairs market and crossing network has a negative effect on the traditional exchange, represented by the Australian Stock Exchange (ASX). [29] Order migration to the upstairs market does not cause increases in information asymmetry, represented by higher bid-ask spread and price impact, in the downstairs market. This makes the upstairs market valuable to investors during times with such market conditions. After controlling for market conditions and trade difficulty the authors find that the price impact of the upstairs market is lower than that of the consolidated limit order book.

O'Hara and Ye (2011) study the effect of US market fragmentation on overall market quality. They use January to June 2006 data on 2754 stocks and find that fragmentation does not harm market quality. This is supported by both the theoretical and empirical studies of Buti, Rindi, and Werner (2010) and Buti, Rindi, and Werner (2011), respectively. However, the findings are also contested by Weaver (2011) who concludes that off-exchange activity has a negative impact on market quality through wider bid-ask spreads and increased volatility. Unfortunately, as they use consolidated data from trade reporting facilities that did not allow them to distinguish between lit and dark off-exchange activity, their study is more of an analysis as to the effect of increased off-exchange activity on market quality.

A recent study by Degryse, de Jong, and van Kervel (2011) investigates the impact of both lit and dark fragmentation on market quality in both global and local order books. Using data on 52 large and mid-cap AEX listed Dutch stocks from January 2006 to 2009 they perform a multivariate panel regression and conclude that overall market quality is reduced when the market share of dark liquidity increases. They improve upon previous studies into market fragmentation, such as O'Hara and Ye (2011), by separately measuring the effects that dark and lit order fragmentation have on market quality. They also focus on the effects resulting from the introduction of multiple trading venues. The authors conclude that while global liquidity does improve overall as a result of lit and

[29] This is later supported amongst the findings of Gresse (2006).

dark order fragmentation, local liquidity is worse off by 10%. Therefore, retail investors who do not have access to SORT or other liquidity aggregating software are worse off.

Ye (2011) examines the non-execution probability and market share of crossing networks. The author extends the literature of cross-sectional variation of transaction costs (Stoll, 2006) to include non-execution in crossing networks. The findings are consistent with the author's theoretical prediction[30] that non-execution probability in crossing networks follows a similar pattern as price impacts in the lit exchange. The author also finds that non-execution probability is positively correlated with price impact, decreases in trading volume, and increases in volatility, which could help provide an explanation for Ray (2010) and Ready (2013).

Gresse (2012) uses a collection of one and two-stage multivariate panel regressions and time series analyses to determine the effects of lit and dark order fragmentation on quoted spreads and depths in both global and local order books. The study improves on previous work by using a more geographically diverse data set, as stocks were compiled from the FTSE100, CAC40, and SBF120 indices. The author concludes that increased dark trading does not have a substantial negative effect on liquidity. While some stocks may experience negative effects in regards to spreads, the effect may be offset by increased depth in these stocks.

Foley, Malinova, and Park (2012) take a slightly different approach to the previous studies and focus on market quality implications of the introduction of hidden orders into a lit exchange.[31] Dark orders were introduced onto the Toronto Stock Exchange (TSX) in April 2011. The introduction resulted in a widening of quoted spreads and an increase in trading costs, measured by the effective spread, leaving depth, volume and volatility unaffected.

Unfortunately all previous studies, with the exception of Foley, Malinova, and Park (2012) are limited by the quality of their measure of dark order fragmentation. Due to the inability to assign dark orders to the reporting firm, dark market fragmentation has only been measured by the degree of dark trading or the proportion of dark trades with the respect to total market activity. In the cases where dark fragmentation is measured explicitly, the studies are performed on a subset of available dark liquidity providers

Results on the effects of dark liquidity fragmentation on market quality, as measure by quoted spreads, are mixed. However, the majority of findings support the idea that increased use of dark liquidity has a negative effect. Fong, Madhavan, and Swan (2004) find that increased off-exchange activity does not result in wider bid-ask spreads. Gresse (2006) finds a more significant effect and

[30] See Ye (2010) – 'A Glimpse in the Dark'.

[31] As mentioned in Section 3.1.4 – 'Exchange Based Pools', hidden orders fall under Exchange Based Pools as they are subject to complete pre-trade transparency since they are involved no third party interaction as in the upstairs markets.

concludes that increased crossing network activity tightens spreads; the results are confirmed in a 2012 study by the author (Gresse, 2012).

Degryse, de Jong, and van Kervel (2011) conclude that higher market share of dark trading is associated with wider quoted spreads, which is consistent with the findings of Nimalendran and Ray (2012) , Weaver (2011), Forde and Putnins (2012), and Foley, Malinova, and Park(2012).

Evidence on the effect of increased use of dark liquidity on depth follows a similar pattern to the evidence on spreads. However, whereas before the majority of evidence concludes that dark liquidity has a negative effect on the particular measure of market quality, evidence now favours the use of dark liquidity. Once again, Gresse (2012) concludes that the effect is positive and depth increases in the lit market, noting, however, that depth may be reduced for smaller stocks. These findings are consistent with those of Buti, Rinder, and Werner (2011). Foucault and Menkveld (2008) also find that the findings resulting from their theoretical model are supported and that increased use of dark liquidity leads to an increase in depth.

In contrast Degryse, de Jong, and van Kervel (2011) propose that depth is reduced in the lit market while Foley, Malinova, and Park (2012) conclude that depth is unaffected.

Current data suggests that in the best case scenario, increased use of dark liquidity leaves volatilities unaffected (Foley, Malinova, and Park, 2012). However, Buti, Rindi, and Werner (2011) and Weaver (2011) find more substantial evidence that fragmentation leads to an increase in short term volatility.

While, as expected, evidence on the effect of dark liquidity on price impact and transaction costs is mixed, it does tend to argue that an increase in the use of dark liquidity results in increased price impact and transaction costs. Fong, Madhavan, and Swan (2004), Degryse, de Jong, and van Kervel (2011), Weaver (2011), Nimalendran and Ray (2011), and Forde and Putnins (2012) find that an increase in dark trading market share leads to an increase in price impacts. This supports the theoretical findings of Zhu (2012).

In contrast, Ye(2011) finds that crossing networks have a lower price impact on trades which is in line with the findings of the author's theoretical model (Ye, 2010).

Studies by O'Hara and Ye (2009), and Buti, Rindi, and Werner(2011) conclude that dark liquidity fragmentation results in lower transaction costs while Conrad, Johnson, and Wahal (2003) deduce that the result is lower realised execution costs.

4.4 Client Composition

The type of clientele allowed access to a dark pool is proven to have a significant effect on the quality of the transactions resulting from that pool. This section identifies the role that exclusivity plays in in determining the quality of a dark pool.

Results inferred from the theoretical model created by Ye (2010) indicate that the inclusion of informed traders on a crossing network negatively effects the price discovery process in the lit exchange.

Zhu (2010) also investigates the role that informed investors play in crossing networks and finds that informed traders are likely to cluster on the heavy side of the market and, therefore, face lower execution probability in the crossing network relative to uniformed investors. This occurs because informed investors often lead to the same conclusions when developing trading strategies as their actions are positively correlated with the value of the assets and, therefore, each other. As a result lit exchanges become more attractive to informed investors while crossing networks become more attractive to uninformed investors. As their lack of correlation in trading habits causes their trades to be more evenly spread across both sides of the market, the use of crossing networks by uninformed investors allows for improved probability of execution.

Boni, Brown, and Leach (2012) examine empirically the role participation constraints play in large trade execution. They hypothesise that more exclusive trading venues should exhibit smaller magnitudes of serial correlation in returns around large trades, less volume and volatility increases prior to large trades, and higher follow-on volume in large trades. They test their hypotheses empirically using 62 days of TAQ data, from January 3 2011 to March 31 2011, from NASDAQ and NYSE listed stocks with a minimum transaction size of 50,000 shares. They find that dark pools targeting buy-side customers experience less serial correlation in returns, less front-running in volume and volatility, and more trade clustering across days. These results can help drive future regulatory discussions as the authors have shown that discrimination based on trade size need not negate any potential benefits from the use of dark pools. [32]

4.5 Determinants of Volume

This section outlines the various findings in determining the factors that affect the level of volume in trading venues offering dark liquidity. They key indicators that affect volume are execution probability, volatility, spread, and lit market volume.

[32] Findings by Nimalderan and Ray(2012) suggest that traders mostly deal in large lots as the majority of dark liquidity volume results from a few large crosses. However, the vast majority of trades consist of small, likely computer generated, orders.

4.5.1 Volatility, Spread, and Volume (Lit)

Ray (2010) models the decision of whether to use a crossing network or traditional quoting exchange to execute transactions in order to derive a list of factors that affect the decision. The author tests the hypotheses empirically and, in accordance with the theoretical findings, concludes that crossing network activity increases and then decreases in the wake of increasing bid-ask spreads and other market liquidity measures. The author also finds that crossing network activity tends to increase when savings on transaction costs outweigh concerns regarding execution uncertainty.

Ready (2013) investigates the determinants of trading volume for NASDAQ listed stocks in the two largest dark pools catering to institutions investors: Liquidnet and POSIT. Consistent with the prediction resulting from the theoretical model developed by Zhu (2012), and consequently inconsistent with Ye (2010), Ready finds that dark pool activity is lower for stocks with higher levels of adverse selection and higher volatility. In addition, dark pool activity tended to be lower for stocks with lower spreads. The results, however, are not monotonic. Ready (2013) finds that dark pool market share initially increases with lit market volume but later decreases while Ray (2010) finds a similar relationship between dark pool market share and relative bid-ask spreads.

Buti, Rindi, and Werner (2011) perform a similar study to Ready (2013) but improve on it by covering more dark pools as well as including more recent and daily volume share data. [33] They use daily stock volume data from 11 dark pools, provided by SIFMA, and perform a Fama-Macbeth cross sectional regression. They determine that dark pools activity is concentrated on liquid stocks and that activity is higher on days with higher depth, lower spreads, and lower volatility. This is consistent with the empirical findings of Ye(2010). These results could be improved upon if they were to cover more than 11 dark pools who voluntarily submitted data to SIFMA as the situation does not allow for independent validation. Also, there is no way of knowing whether these dark pools represent the same fraction of total dark trading over time.

4.5.2 Execution Probability

Resulting from theoretical modelling, Ye (2010) concludes that an increase in fundamental uncertainty in the value of an asset increases price impact in the lit exchange and lowers probability of execution in the crossing network. While one assumes that this would lower volume in the crossing network, it actually has the opposite effect. The author argues that the event creates a comparative advantage for crossing networks and results in an increase in market share. As always, in contrast to the theoretical findings of Ye (2010) are the theoretical findings of Zhu (2012) who finds that higher order imbalances, resulting in lower execution probability, lead to lower trading volume on the crossing network.

[33] Even though Ready's current version is 2013 there was a working copy available when Buti, Rindi, and Werner developed their study.

In line with the findings of Zhu (2012), Buti, Rindi, and Werner (2011) used SIFMA data from 11 anonymous dark pools to conclude that higher order imbalance resulting in lower probability of execution are negatively related to dark pool market share.

4.6 Adverse Selection

Adverse selection refers to the situation in which an investor executes a trade only to have the price move in the same direction shortly after, resulting in the trade executing at a less favourable price had the investor waited. It also refers to situations in which low participation rates prevent the investor from completing a transaction prior to an adverse price change. It is a topic of recent interest in dark pools as the costs associated with adverse selection are argued to be material (Kratz and Schoneborn, 2010). Some authors argue that the benefits gained from executing trades in a crossing networks are immediately lost to adverse selection (Altunata, Rakhlin, and Waelbroeck, 2010, and Naes and Odegaard, 2006).

Unfortunately, adverse selection in a dark pool environment is no longer easy to detect. Buy-side traders accessing multiple dark pools through liquidity sourcing technology find it difficult to break down results by pool as trades are often split into a series of smaller transactions. Adverse selection is also observed to occur over a shorter time frame, second and minutes as opposed to hours, making it more difficult to detect visually (Saraiya and Mittal, 2009).

In a 2009 paper, Saraiya and Mittal educate buy-side dark pool participants on the negative effects adverse selection can have on returns. They find that adverse selection occurs systematically across all dark pools. They also find that increased high-frequency trading activity results in greater levels of adverse selection across all examined dark pools. Dark pools that previously excluded high-frequency trading activity, only to allow it later, experience a growth in volume. Unfortunately, incidents of adverse selection are also proportional to trading volume in dark pools and, as a result, the quality of trades in dark pools suffers. The authors advise investors to investigate the quality of the dark pools they use and rank them in order to access liquidity from pools on an increasing scale of toxicity.[34]

In their paper titled 'Adverse Selection vs. Opportunistic Savings in Dark Aggregators', Altunata, Rakhin, and Waelbroeck (2010) educate the audience regarding when to use dark aggregators as opposed to other opportunistic savings strategies. Using employer capital they conduct a series of trades and analyse the results. They conclude that opportunistic algorithms have lower shortfalls than structured models, especially when markets are volatile. However, this increases the investors' exposure to problems arising from adverse selection. They advise investors employing dark

[34] For more information on how to judge the quality of a pool see Mittal (2008) "Are you playing in a toxic dark pool?".

aggregators to do so tactically and with limited exposure times in order to minimize costs associated with adverse selection.

Zhu (2012) argues, in a theoretical context, that while an increase in informative orders leads to better price discovery it occurs at the expense of an increase in adverse selection. Empirically, Forde and Putnins (2012) find that an overall increase in dark trading activity increases adverse selection.

5.0 Motivation Behind Study

If financial markets are not fair and safe, they will not attract investors and will fail to provide companies with the capital they seek. Over half of the USA's residents report that they own stock directly or through investment vehicles and, according to Mary Jo White of the Consumer Federation of America, this is representative of all developed economies. This implies that the majority of households in developed economies are directly connected to the securities market. Without retail investor participation, financial markets will no longer be able to accurately price stocks as they will be deprived of price improving information contained in retail investor trades. As a result, financial markets will collapse because investors will not be willing to trade based on prices they believe to be inaccurate and corporations themselves will close due to the high cost of, now scarce, investment capital. The result will be a collapse of the financial markets. Therefore, comprehensive regulatory policies must be adopted in order maintain investor confidence and support our financial markets.

Current literature could benefit from explicitly measuring extent of fragmentation in the dark order book market. As previously mentioned, Figure 1 breaks down the market shares of known dark liquidity providers, as reported by Thomson Reuters Market Share Reporter. As indicated by the proportion of combined broker crossing system activity, 49% of the total reported dark transactions cannot be assigned to a particular trading venue. These trades appear under the Systematic Internalizer (SI) and Over-The-Counter (OTC) flags within the Markit BOAT consolidated tape. As a result, previous studies resort use the overall proportion (market share) of dark trading with respect to total trading volume, both lit and dark, as a proxy for dark trading and/or dark order book fragmentation. Therefore, previous studies examine the market effects resulting from increased amounts of dark trading but not the level of fragmentation in the dark order book market. They do not determine whether the effects are due to more dark trading as a whole or to the fact that dark trading is occurring across a wide variety of venues as opposed to a central location. We assign owners to the trades and calculate a fragmentation measure similar to the one used for lit order book markets where each trade can be assigned to a trading venue. [35]

[35] See Section 8.2.1 for information on how we calculate the fragmentation measure.

Our study also takes into consideration implicit consolidation resulting from 2 venues sharing access to their order books. This results in a more accurate dark fragmentation measure which better reflects the state of fragmentation in the dark order book market.[36]

We also provide more accurate measurements for variables whose values are derived from the limit order book. Previous studies such as Foucault and Menkveld (2008) and Degryse, de Jong, and van Kervel (2011) use 5 or 1 minute snapshots of the limit order book, respectively, when determining values for spread, depth, and price impact. However, the Thomson Reuters Tick History Database provides millisecond snapshots of limit order books that display information on the top 25 bid and ask prices. Therefore our study more accurately calculates time sensitive measurements, such as price impact and realised spread, by referencing midpoints that are exactly 1 second from the time of the actual trade, accurate to the millisecond. The 1 second interval is chosen as it is found by Henker and Wang (2006) to be an improvement to the widely accepted '5-second rule' used for matching quotes with transactions. We also use the more frequent order book information to determine the average spreads and depths resulting in more accurate measurements; as opposed to averaging 1 minute snapshots, where the effects can be lost over such a long time-frame, we average 1-second snapshots.

6.0 Hypotheses

We test the effect of fragmentation of order books. Fragmentation can take three major forms:

1. Fragmentation within the lit order book.
2. Fragmentation between lit and dark order books (i.e. the migration of trades from the visible to the non-displayed liquidity market).
3. Fragmentation within the dark order book.

Our resulting hypotheses are as follows:

Lit market:

Hypothesis 1. Increased competition among visible order book exchanges resulting from increasing lit market fragmentation leads to a decrease in quoted depths, quoted spreads, realised spreads, and effective spreads.

The introduction of MiFID leads to the formation of new markets, known as multilateral trading facilities (MTFs), which offer lower transaction costs over traditional exchange as

[36] See Section 7.4 – 'Fragmentation Data' for more information on the fragmentation and consolidation process.

well as rebates for market makers.[37] *Competition effects lead to discounts and competitive pricing as exchanges compete for order flow.* (Fong, Madhavan, and Swan, 2004, and Foucalt and Menkveld, 2008). *As a result of the increased competition,* [38] *traditional exchanges, such as the London Stock Exchange (LSE), lower transaction costs as well as introduce their own rebate policies;*[39,40] *however they still cannot match the cost savings offered by their newly formed competitors such as BATS Europe, CHI-X Europe, and Turquoise. Local order book spreads tighten as the primary exchange's (LSE) rebates lower the cost of a round-trip transaction for market makers; however depth would decrease as not all participants can benefit from the rebate.*[41] *Global order books spreads tighten as MTFs compete with each other, as well as with the primary exchange, by lowering fees for liquidity takers*[42] *and offering rebates for liquidity makers.*[43] *As some venues offer higher rebates than others, thus further lowering transaction costs for market makers, not all market makers, especially those in more expensive venues, will be able to tighten their spreads to the same extent. Therefore, best bid/ask spreads will be tighter for the least expensive venues resulting in lower depth at the best rates. As a result of the reduction in quoted spreads, realised spread and effective spreads decrease, signifying a decrease in the cost of a round trip transaction, with the effects being greater for global order books compared to local order books for the same reasons as we outline for quoted spreads.*

Dark Market:

Hypothesis 2. An increase in dark market share, resulting from the migration of trades from the lit to dark order book, leads to wider spreads and greater price impact, with the effect being greater for smaller firms.

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[37] As noted in the Pricewaterhouse Coopers report by Caplan et. al. – 'Dark pools of Liquidity' (http://www.pwc.com/us/en/alternative-investment/assets/NY-10-0105-PwC-alt-Caplan.pdf).

[38] Competition for market makers exists because they can operate across multiple venues as well as switch venues. This is made possible because becoming a market maker is the result of an application process, rather than by appointment, in all lit trading venues in this study.

[39] LSE adopts market maker rebate to boost liquidity (http://www.thetradenews.com/newsarticle.aspx?id=1750).

[40] The phenomenon of lowering prices to attract liquidity was also noted by Foucault and Menkveld(2008).

[41] The LSE is partially a quote driven market meaning it allows both market makers and individual traders to post quotes. As retail investors cannot meet the volume requirements and are usually liquidity takers they can seldom benefit from these discounts.

[42] BATS Europe lowers liquidity taker fees to attract customers (http://www.thetradenews.com/news/Asset_Classes/Equities/BATS_Europe_ups_price_war_with_new_taker_fee.aspx).

[43] Turquoise raises rebates to help improve liquidity (http://www.thetradenews.com/news/Asset_Classes/Equities/Turquoise_hikes_maker_rebates_to_reverse_downturn.aspx).

Dark orders are found to contain information (Forde and Putnins, 2012, Nimalderan and Ray, 2012), especially those of smaller firms (Nimalderan and Ray, 2012). This results in asymmetric information among market participants which leads to a reduction in their confidence in advertised prices. Lack of confidence in advertised prices is conveyed by a widening of quoted spreads and an increase in price impact. This effect will be greater for lower index firms[44] as they are less liquid and, as a result, their trades contain more information (Nimalderan and Ray, 2012).

Hypothesis 3. Increased fragmentation of the dark order book market leads to tighter quoted spreads in visible order books.

As dark order books fragment, the result is a reduction the probability of execution as matching dark orders are less likely to reside in the same pool as the original transaction(Buti, Rindi, and Werner, 2010, and Zhu, 2012); more dark venues results in more places for matching transactions to go making them less likely to be found in your pool. As a result, dark trades that contain information (Forde and Putnins, 2012, Nimalderan and Ray, 2012) are relegated to the visible order market to execute. Therefore, in fragmented dark order book markets, more informative trades reach the visible order book and convey their information to the public, resulting in greater confidence in the advertised price represented by tighter quoted spreads

7.0 Data

The following sections outline the data and variables that are used in the study. Information on trades as well as the status of limit order books is gathered from the Thomson Reuters Tick History database via SIRCA. We conclude the section by summarising trading activity throughout the study period.

7.1 Sample of Stocks

As a result of the introduction of MiFID, UK stocks have fragmented across both lit and dark liquidity venues, while maintaining significant daily trading volumes across multiple venues, making them a perfect choice for this study. We focus on a sample of large-cap UK stocks, limiting our sample to the constituents of the FTSE-100 index. Table 1 contains information on the possible candidates for the study. We exclude companies that are not continuously part of the index throughout the entire observation period. We also remove companies that qualify as financial stocks according to Global

[44] In our study lower index firms refer to constituents of the FTSE-100 index with a market capitalisation less than £10 billion while upper index firms are those with a market capitalisation greater than £10 billion (see Section 7.0)

Industry Classification Standards (GICS).[45] The final sample includes 51 companies In order to observe whether the size of the firm affects the findings we split the FTSE-100 firms into 2 groups. Companies with an average market capitalisation during the study of at least £10billion are hereby classified as upper index firms while the remainder are classified as lower index firms. The result is 24 upper index firms and 29 lower index firms, as indicated in Table A1 of Appendix A.

7.2 Time Frame

The time frame for the study is November 1 2005 to October 31 2011. This time frame is ideal as it consists of three very distinct periods of fragmentation and consolidation within the European equity market:

1. *Pre MiFID (November 1 2005 to October 31 2007)* – Very few fragmentation or consolidation events during this period.

2. *Intro to MiFID (November 1 2007 to October 31 2009)* - Multiple events of fragmentation in both the lit and dark liquidity markets

3. Post MiFID (Maturity) – November 1 2009 – October 31 2011 – Multiple fragmentation events across lit and dark liquidity markets as well as multiple consolidation events for dark liquidity markets.[46]

The aforementioned study period contains examples of all three fragmentation events that we are testing, as indicated within our hypotheses, which makes it an ideal sample period for this fragmentation study.

We include only those transactions that occur between the times of 800 and 1630, standard UK exchange trading hours.

7.3 Transaction Data

In order to determine daily transaction levels for the various stocks included in the study we source transaction level data for our study period from the Thomson Reuters Tick History Database via Sirca. The following variables are required for each transaction in order to complete our study:

1. *Stock Traded* – An identifier that indicates the firm whose stock is traded
2. *Date* – The date of the transaction
3. *Time* – The time of the transaction (accurate to the nearest millisecond)
4. *Exchange* - The venue from which the transaction originates

[45] Financial stocks are reported to have very specific factors that drive their liquidity and volatility and, therefore, do not follow the same behavioural pattern as non-financial stocks (Gresse, 2012).
[46] See Section 7.4 for information about the specific events and how they are incorporated into the study.

5. *Price* – The price per share
6. *Quantity* –The number of stocks in the transaction
7. *Qualifier* – An identifier that supplies some additional information about the transaction (e.g. originates from dark pool, uncrossing trade etc.)

Transaction data is gathered for each stock indicated in Table A1 and consists of transactions from the dark and lit liquidity providers indicated in Table 1 below.

The list of dark venues, however, is not exhaustive, and only contains the dark venues for whom we can explicitly observe transactions. [47]

In addition to the exchange codes, qualifiers, such as those found in Table A2 of Appendix A, are used to help classify transactions as dark or lit when they do not necessarily originate from an exclusively dark venue or to identify transactions that should be excluded from the study. For example, the Chi-X is listed as both a lit and dark liquidity provider. In order to classify Chi-X trades as those that consume dark liquidity we look for Chi-X transactions that contain one of the acceptable qualifiers from Table A2.

In certain cases a suffix is applied to the RIC for a stock to indicate that trades that include this suffix originate from dark liquidity. For example, British Petroleum (RIC = BP) may use BP as the firm identifier to indicate a transaction using visible liquidity and BPp to indicate a transaction using dark liquidity.

Some qualifiers are used to identify transactions that we ignore. Qualifiers of '4' and 'RCK' indicate cancelled transactions. Qualifiers of 'U' indicate uncrossing transactions used by market makers to close their positions at the end of the trading day, and as such do not contain any information about investors.

[47] See Section 8.2.1 – 'Regressors' for information on how we incorporate the trades whose venue of origin cannot be identified.

Table (1) Trading Venues

The table identifies the lit and dark liquidity providers that explicitly report transaction information and their unique Reuters Instrument Code (RIC). When a provider explicitly reports transactions it means that the venue from which the transaction originates is identified. The list of dark venues does not contain venues that report transactions to the consolidated tape as we handle that separately (See Sections 7.4 and 8.2.1). Some exchanges, such as the London Stock Exchange, are found in both lists and this occurs when a visible liquidity providers also offers dark liquidity and identifies such transactions through the aid of a qualifier.

Exchange List			
Lit		**Dark**	
Exchange Name	**RIC**	**Exchange Name**	**RIC**
London Stock Exchange	L	London Stock Exchange	L
BATS	BS	Berlin SE	BE
Chi-X	CHI	Blink	BLNK
Equiduct	ED	BlockMatch	BLOX
NYSE ARCA	HFT	BATS Dark	BS
Instinet	INS	CHI-X Dark	CHI
NASDAQ OMX	NQX	RWB	D
Plus Markets	PZ	Xetra	DE
Quote MTF	QMF	Frankfurt	F
Turquoise	TQ	Hamburg	H
		Instinet	INS
		Liquidnet	LIQU
		Munich	MU
		NASDAQ OMX	NQX
		NYSE Euronext	NXEU
		NYFX Millenium	NYFX
		Paris	PA
		Plus Markets	PZ
		Stuttgart	SG
		Sigma-X	SIG
		Turqiouise	TQ
		Virt-X	VX
		Posit	XPOS
		XUBS	XUBS

7.4 Fragmentation Data

In order to construct the measure of fragmentation in the dark order books market, as described in Section 8.2.1, we begin by constructing a timeline of the various consolidation and fragmentation events, found in Table A3 of Appendix A. These events and their contributions to the study are defined as follows:

Fragmentation events occur when new dark trading venues are introduced into the market. The result is an increase in the total number of dark trading venues. For example, there are four distinct dark trading venues and then Turquoise launches its TQDark dark pool. There are now five distinct dark trading venues. These events are required in order to identify and approximate the number of firms reporting to the consolidated tape. Fragmentation events do not need to be identified for explicitly reporting dark venues as the date in which the

trading venue began operating can be defined from the transaction data itself and does not need to be approximated.

Figure 2 contains information on the number of trading venues operating both displayed and non-displayed order books during our study period. Increases in lit, consolidated and unconsolidated measures indicate the introduction of new trading venues. In some cases we see an immediate inclusion of more than one dark trading venue. This either occurs when Markit BOAT fails to announce an individual trading venue's inclusion in the consolidated tape, and their inclusion is only discovered during a later announcement, or when there is a cancellation in the liquidity partnership between multiple firms. An example of the former event occurs in June 29 2010 and can be observed in Figure 2. Firms do not always provide press releases when joining the consolidated tape. As a result, when a report is finally made, there are sometimes multiple other trading venues that need to be included in the consolidated tape, which results in a greater increase to the number of reporting firms. This is a limitation to the measure and results from imperfect reporting by the trading venues or trade reporting firms.

An example of the latter fragmentation event can be found on November 30 2009. The Euro Million dark pool was responsible for facilitating the consolidation of multiple venues' order books. While in operation several venues operated a single order book if liquidity sharing due to consolidation was considered. When the Euro Million dark pool closed the liquidity partnership was cancelled as well. As a result, the 6 firms that were part of this liquidity sharing partnership went back to operating their own order books and the number of unique order books increased significantly.

Consolidation events occur when dark trading venues decide to share their order books. These events are recorded for both explicitly reporting dark trading venues as well as those that report to the consolidated tape as both are able to participate in liquidity sharing schemes with other venues. For example, there are five distinct dark trading venues and Smartpool (XSMP) and TQDark (TQD) decide to share their dark order books. As a result XSMP clients have access to liquidity on the TQD order book, and vice versa. Since the two order books have consolidated the result is one unique order book as clients of both dark pools have access to the shared liquidity. This results in a decrease in the number of distinct liquidity providers from five to four and can be identified in Figure 2 by a decrease in the number reporting firms under the consolidated (dark) measure.

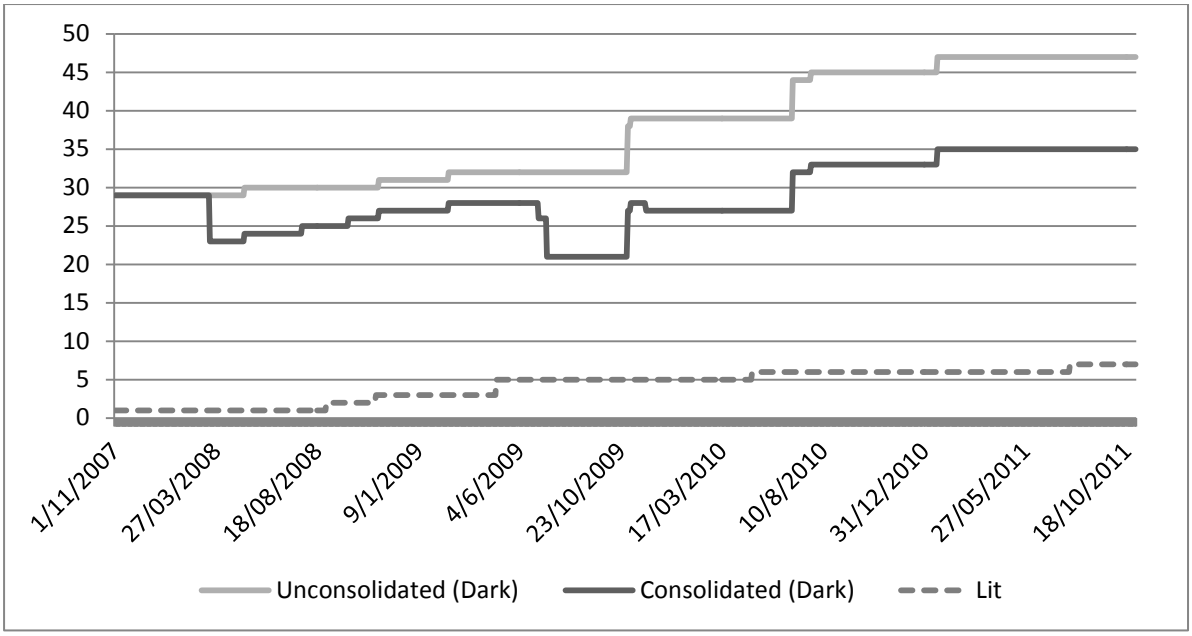


Figure (2) Number of trading venues

The figure shows the number of trading venues from which investors can source both lit (displayed) and dark (non-displayed) liquidity. The number of dark liquidity venues is conveyed using two measures: the unconsolidated measure which reports the explicit number of dark trading venues, and the consolidated measure which takes into consideration implicit consolidation through liquidity partnerships. As venues begin to share liquidity they implicitly consolidate and their transactions are attributed to the new consolidated pool as opposed to the individual firms themselves. The data is collected from the introduction of MiFID on November 1 2007 until the final date in our study, October 31 2011.

> But we must also consider the situation where, for example, XSMP decides to share its liquidity with TQD customers as well as Instinet BlockMatch (BLOX) customers, but TQD and BLOX do not share liquidity with each other. This results in three trading venues becoming two unique trading venues as one venue contains the interaction of trades between XSMP and TQD and the other contains the interactions of trades between XSMP and BLOX. As a result, half of the XSMP liquidity will be consolidated with TQD while the other half will be consolidated with BLOX.

We use the timeline in Table A3 of Appendix A to consolidate daily market shares for firms whose order books have been implicitly merged (i.e. as a result of liquidity sharing).

7.5 Quote Data

In order to calculate the various market quality measures described in Section 8.1 we first gather the necessary data from Thomson Reuters Tick History via Sirca. Luckily, Thomson Reuters provides snapshots of the order book as part of its Market Depth data series, accurate to the nearest millisecond. As a result we are able to retreive information on the status of multiple venues' limit

order books, including the price and quantity of shares offered at various depth levels within the order book, without having to reconstruct the order books manually.

For our study we gather quote data for the 52 firms[48] where the quotes originate from the lit (quote-based) venues identified in Table 1. We use information pertaining to the top 25 levels of the order book in order to perform analysis on the availability of shares deeper within the order book, as opposed to simply at the best price level. The following variables are collected for each order book:

1. *Stock* - An identifier that indicated the firm to whom the quote pertain
2. *Date* – The date of the current snapshot
3. *Time* – The time of the current snapshot
4. *Exchange* – The exchange that advertises the quotes
5. *Bid Price* – The price at which investors can sell shares
6. *Bid Quantity* – The number of shares available at the current bid price
7. *Bid Number of Investors* – the number of investors at the current bid price
8. *Ask Price* – The price at which investors can purchase shares
9. *Ask Quantity* – The number of shares available at the current ask price
10. *Ask Number of Investors* – The number of investors at the current ask price[49]

7.1.1 Limit Order Books (Global vs. Local)

We follow the approach of Degryse, de Jong, and van Kervel (2011) and Gresse (2012) and distinguish between global and local order books. The local order book refers to the primary exchange while the global order book is comprised of quotes from all available lit exchanges. The distinction is made in order to take into consideration the fact that some customers, predominantly retail investors, cannot afford access to algorithms that simultaneously source liquidity across multiple venues. As a result, they will not have access to the consolidate order book that institutional investors have access to. Therefore, it is important to examine both local and global order books in order to determine how retail and institutional investors, respectively, will be affected by market fragmentation and dark liquidity.

Local order book information is gathered by referencing the status of the London Stock Exchange (LSE) order book, as provided by Thomson Reuters, at a given point in time. The global order book, however, is constructed by merging the snapshots of all available lit exchanges. That is, if the LSE is posting a best bid of £110.5, with a quantity of 150 shares, while Turquoise is posting a best bid of £110.5, with a quantity of 100 shares, the global limit order book will display a best bid price of £110.5, with a quantity of 250 shares. However, any exchanges that do not post an update to their

[48] 53 firms if we include the two classes of Royal Dutch Shell shares (A and B).
[49] All bid and ask measures were gathered for each of the 25 levels of the order book.

order book at least every 30 seconds will be removed from the consolidated order book. This is done to ensure that we do not use out of date prices for stocks as this can lead to negative spreads when combining multiple order books.

7.6 Trading Activity

An analysis of the transaction data indicates that dark trading has grown slowly since the introduction of MiFID on November 1 2007. From Figure 3 we observe an immediate increase in dark trading amongst the constituents of the FTSE-100 index following the introduction of MiFID. The spike in dark trading can not only be attributed to the launch of several dark liquidity providers, but to new MiFID trade reporting regulations which require that all off exchange transactions be reported either directly by the exchange or submitted for reporting to the primary exchange (e.g. LSE) or trade reporting facility (e.g. Markit BOAT). Prior to November 1 2007 the measures are subdued due to the lack of emphasis on trade reporting by regulatory bodies; a situation that was corrected by the second MiFID directive.

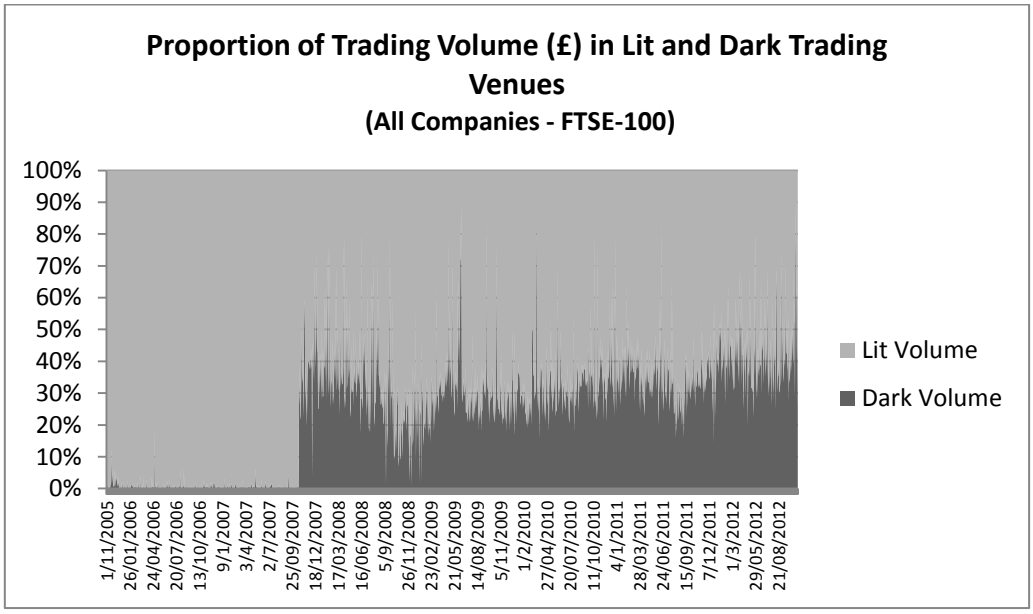


Figure (3) Proportion of lit and dark trading volume in FTSE-100 stocks

The figure shows the proportion of total daily trading volume, as measured by the total value of stocks traded in British Pounds Sterling (£), in lit order book markets compared to dark order book markets for all constituents of the FTSE-100 index.

Table 2 presents transaction activity data across both lit and dark markets throughout the study period. In Table 2 we see that from the pre-MiFID period of November 1 2005 to October 31 2007 until the end of the introduction of MiFID period of November 1 2007 to October 31 2009 there is a significant contraction in the visible order market, as indicated by a decrease in the average daily lit trading volume per firm from £80.47 to £64 million. However, the average daily trading volume, dark

and lit, in British Pounds Sterling (£) per firm remains fairly constant, moving from £86.47 million to £87.53 million. The average daily number of lit transactions more than doubles over the two periods, from 2.61 thousand to 7.23 thousand while the average lit transaction size in British Pounds Sterling (£) falls by nearly three quarters, from £25.43 thousand to £7.68 thousand. Over the same two periods we observe, in Table 2, a significant increase in daily dark trading in terms of the number of transactions and trading volume from 90 to 520 transactions and from £6 thousand to £25.53 thousand, respectively. A 60% decrease in average transaction sizes over the period from £188.56 thousand to £76.15 thousand, while not as large as that experienced by lit markets, is still significant.

Following a drop in proportion of dark trading during the initial months of the Global Financial Crisis (GFC), as indicated by Figure 3, the proportion of dark trading activity has seen steady growth. This is supported by the findings in Table 2 that indicate an increase in the proportion of dark activity from 28.89% to 29.4% over the final two study periods after which MiFID has been introduced. The rise in the proportion of dark liquidity used is more dramatic in the first two study periods, increasing from 8.14% to 25.89%. However, as mentioned previously, we must use caution with the pre-MiFID dark trading figures as reporting standards did not require all dark transactions to be reported.

During the two post-MiFID periods, overall trading volume in British Pounds Sterling (£) contracts slightly in lit markets, reducing from £64 million to £62.09 million, while dark market trading volume increases from £25.53 million to £26.37 million. This is coupled with further decreases to the average trade size and increases to the number of transactions across both dark and lit trading venues, most notably a decrease in the average dark transaction size from £76.16 thousand to £25.33 thousand. Upon further inspection of Table 2 we see that all aforementioned patterns are replicated for both upper and lower index firms.

To further investigate the issue of decreasing dark transaction sizes we turn to Figures 4 and 5. From Figure 4 we can see that the majority of volume in British Pounds Sterling (£) in dark order book markets results from large transactions of £100,000 or greater. However, the proportion of trading volume in British Pounds Sterling (£) resulting from transactions of £100,000 or greater is on the decline, with the dark market being increasingly used to execute transactions of less than £100,000.

Table (2) Average daily trading activity across lit and dark trading venues

The table shows the average daily number of transactions and trading volume, measured in British Pounds Sterling (£), for FTSE-100 constituents in both lit and dark trading venues, as well as across the consolidated lit and dark markets. Results are displayed separately for high and low market capitalisation FTSE-100 companies as well as for the index as a whole. The data is divided into the 3 distinct periods representing the stages of adoption of MiFID policies: Pre-MiFID (November 2005 – October 2007), Introduction of MiFID (November 2007 – October 2009) and Post/Maturity of MiFID (November 2009 – October 2011).

		Number of Transactions (thousands)	% of Total	Volume (GBP) (millions)	% of Total	Average Trade Size (GBP) (thousands)
Lit						
	Nov2005-Oct2007	2.61	95.48%	£80.47	91.86%	£25.43
		(0.01)		(0.74)		(0.16)
	Nov2007-Oct2009	7.23	91.84%	£64.00	74.11%	£7.68
		(0.04)		(0.50)		(0.03)
	Nov2009-Oct2011	10.11	87.37%	£62.09	70.60%	£5.17
		(0.06)		(0.49)		(0.01)
	Total	6.35	92.72%	£64.18	77.60%	£12.51
		(0.09)		(0.53)		(0.24)
Dark						
	Nov2005-Oct2007	0.09	4.52%	£6.00	8.14%	£188.56
		(0.00)		(0.10)		(4.16)
	Nov2007-Oct2009	0.52	8.16%	£23.53	25.89%	£76.16
		(0.01)		(0.24)		(2.59)
	Nov2009-Oct2011	1.26	12.63%	£26.37	29.40%	£25.33
		(0.01)		(0.25)		(0.23)
	Total	0.63	7.28%	£18.73	22.40%	£97.14
		(0.02)		(0.34)		(2.82)
Lit + Dark						
	Nov2005-Oct2007	2.70		£86.47		£27.21
		(0.01)		(0.78)		(0.17)
	Nov2007-Oct2009	7.76		£87.53		£10.18
		(0.04)		(0.67)		(0.05)
	Nov2009-Oct2011	11.37		£88.46		£6.95
		(0.06)		(0.66)		(0.03)
	Total	6.99		£82.92		£14.48
		(0.11)		(0.59)		(0.24)

		Number of Transactions (thousands)	% of Total	Volume (GBP) (millions)	% of Total	Average Trade Size (GBP) (thousands)
Lit						
	Nov2005-Oct2007	3.59	98.35%	£136.15	94.71%	£34.10
		(0.02)		(1.49)		(0.23)
	Nov2007-Oct2009	10.54	94.65%	£113.34	76.65%	£10.43
		(0.07)		(0.99)		(0.06)
	Nov2009-Oct2011	15.54	90.15%	£109.58	72.89%	£6.55
		(0.12)		(0.97)		(0.02)
	Total	9.84	94.43%	£119.59	81.59%	£17.10
		(0.05)		(0.68)		(0.11)
Dark						
	Nov2005-Oct2007	0.06	1.65%	£8.67	5.29%	£209.12
		(0.00)		(0.20)		(6.52)
	Nov2007-Oct2009	0.61	5.35%	£39.16	23.35%	£94.03
		(0.01)		(0.49)		(5.86)
	Nov2009-Oct2011	1.70	9.85%	£44.28	27.11%	£30.76
		(0.03)		(0.51)		(0.33)
	Total	0.78	5.57%	£30.36	18.41%	£111.51
		(0.01)		(0.26)		(2.95)
Lit + Dark						
	Nov2005-Oct2007	3.65		£144.82		£35.64
		(0.02)		(1.56)		(0.24)
	Nov2007-Oct2009	11.15		£152.50		£13.47
		(0.08)		(1.34)		(0.08)
	Nov2009-Oct2011	17.25		£153.86		£8.58
		(0.13)		(1.30)		(0.06)
	Total	10.62		£149.95		£19.29
		(0.06)		(0.81)		(0.11)

		Number of Transactions (thousands)	% of Total	Volume (GBP) (millions)	% of Total	Average Trade Size (GBP) (thousands)
Lit						
	Nov2005-Oct2007	1.89	93.39%	£40.02	89.79%	£19.12
		(0.01)		(0.46)		(0.21)
	Nov2007-Oct2009	4.91	89.87%	£29.35	72.32%	£5.75
		(0.03)		(0.18)		(0.03)
	Nov2009-Oct2011	6.28	85.41%	£28.60	68.98%	£4.19
		(0.03)		(0.18)		(0.01)
	Total	4.36	89.56%	£32.64	77.01%	£9.67
		(0.02)		(0.18)		(0.08)
Dark						
	Nov2005-Oct2007	0.11	6.61%	£4.06	10.21%	£173.63
		(0.00)		(0.10)		(5.40)
	Nov2007-Oct2009	0.46	10.13%	£12.55	27.68%	£63.61
		(0.01)		(0.15)		(1.60)
	Nov2009-Oct2011	0.95	14.59%	£13.75	31.02%	£21.49
		(0.01)		(0.14)		(0.30)
	Total	0.51	10.44%	£10.13	22.99%	£86.13
		(0.01)		(0.08)		(1.90)
Lit + Dark						
	Nov2005-Oct2007	2.00		£44.08		£21.08
		(0.01)		(0.46)		(0.21)
	Nov2007-Oct2009	5.37		£41.90		£7.87
		(0.03)		(0.28)		(0.04)
	Nov2009-Oct2011	7.23		£42.34		£5.80
		(0.03)		(0.27)		(0.03)
	Total	4.87		£42.77		£11.57
		(0.02)		(0.20)		(0.08)

The pattern can also be observed for average transaction sizes and number of transactions in Table 2 and Figure 5 respectively. From Table 3 we can see that, relative to dark orders of other sizes, dark orders below £10,000, including those below £200, are growing in terms of both the number of transactions and the daily volume in British Pounds Sterling (£) with increases of 11% and 6% amongst dark orders, respectively. Large dark transactions of over £100,000 is the only category that is not only shrinking in terms of number of transactions but in average daily volume in British Pounds Sterling (£) as well, following an initial spike in both measures following the introduction of MiFID. This indicates that while the dark market is intended to provide a safer executing environment for large market moving orders, participants are choosing to segment their orders into smaller portions in order to either guarantee transaction execution or further conceal their large orders using series of smaller orders and liquidity sourcing technology. Prior to the introduction of MiFID the dark order book market was dominated primarily by medium and large sized order of at least £10,000, in terms of both volume in British Pounds Sterling (£) and the number of transactions.

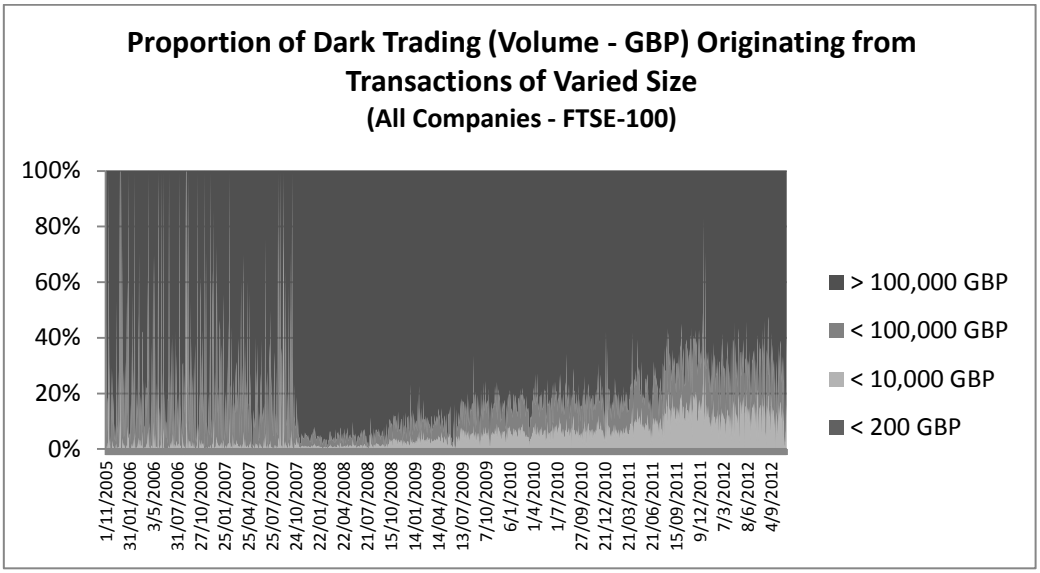


Figure (4) Proportion of dark volume originating from transactions of varied size for FTSE-100 stocks

The figure shows the average daily proportion of dark volume per firm, measured in British Pounds Sterling (£), originating from transactions of varied size for FTSE-100 stocks. Transactions are split into 4 groups. Micro transactions are those of 200 British Pounds Sterling (£) or less and represent automated trades. Small transactions are those greater than 200 British Pounds Sterling (£) up to 10,000 British Pounds Sterling (£) and represent retail investor activity. Medium size transactions are those greater than 10,000 British Pounds Sterling (£) and up to 100,000 British Pounds Sterling (£) and represent a mix of larger retail investor and smaller institutional investor trades. Large transactions are those over 100,000 British Pounds Sterling (£) and represent institutional investor trades.

Figure 5 and Table 3 also indicate the rise in micro transactions; transactions below £200. These transactions are the result of automated trades as investors would not waste time and money on such small transactions. Unfortunately we cannot guarantee whether the micro transactions are detecting large order in the market or simply interacting with each other. However, it is unlikely that transactions of such small size are detecting liquidity in large orders. Through the use of minimum trade size parameters, investors attempting to conceal a large transactions by splitting an order into a series of small transactions would not want to execute in such small blocks. Such small minimum trade sizes are not only inconvenient but also expose investors to predatory algorithms that use small transactions to try and detect large standing orders.

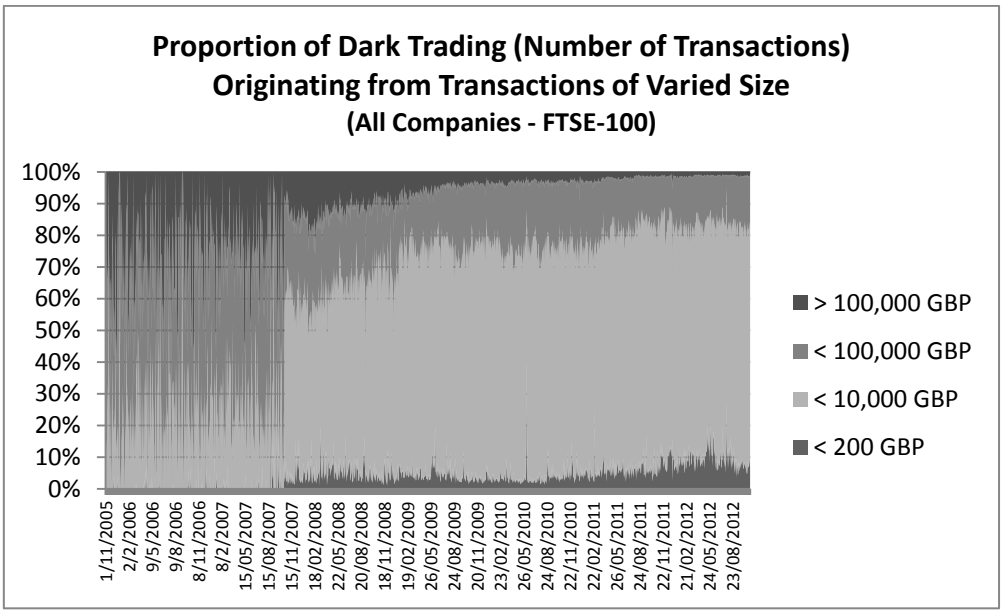


Figure (5) Proportion dark trades originating from transactions of varied size for FTSE-100 stocks

The figure shows the average daily proportion of dark trades per firm, measured by the number of transactions, originating from transactions of varied size for FTSE-100 stocks. Transactions are split into 4 groups. Micro transactions are those of 200 British Pounds Sterling (£) or less and represent automated trades. Small transactions are those greater than 200 British Pounds Sterling (£) up to 10,000 British Pounds Sterling (£) and represent retail investor activity. Medium size transactions are those greater than 10,000 British Pounds Sterling (£) and up to 100,000 British Pounds Sterling (£) and represent a mix of larger retail investor and smaller institutional investor trades. Large transactions are those over 100,000 British Pounds Sterling (£) and represent institutional investor trades.

Further investigation is necessary to determine why overall transaction sizes are on the decline in both lit and dark liquidity markets while the number of transactions is increasing. However, it is our understanding that this phenomenon can be largely attributed to the advent of automated trading, predominately the adoption of Smart Order Routing Technology (SORT).

Table (3) Average daily activity in lit and dark trading venues for transactions of varied size for FTSE-100 stocks

The table shows the average daily number of transactions and trading volume (with corresponding standard errors in brackets below each figure), measured in British Pounds Sterling (£), for transactions of varied size for FTSE-100 constituents in both lit and dark trading venues, as well as across the market as a whole. The data is divided into the 3 distinct periods representing the stages of adoption of MiFID policies: Pre-MiFID (November 2005 – October 2007), Introduction of MiFID (November 2007 – October 2009) and Post/Maturity of MiFID (November 2009 – October 2011).

		< 200 GBP						< 10,000 GBP						< 100,000 GBP						> 100,000 GBP					
		Number of Transactions (thousands)	% of Total	% of Lit/Dark	Volume (GBP) (millions)	% of Total	% of Lit/Dark	Number of Transactions (thousands)	% of Total	% of Lit/Dark	Volume (GBP) (millions)	% of Total	% of Lit/Dark	Number of Transactions (thousands)	% of Total	% of Lit/Dark	Volume (GBP) (millions)	% of Total	% of Lit/Dark	Number of Transactions (thousands)	% of Total	% of Lit/Dark	Volume (GBP) (millions)	% of Total	% of Lit/Dark
Lit																									
	Nov2005-Oct2007	0.05 (0.00)	1.87%	2.04%	£0.00 (0.00)	0.01%	0.01%	1.26 (0.00)	50.42%	51.07%	£5.48 (0.02)	11.49%	12.10%	1.20 (0.01)	40.58%	41.15%	£34.79 (0.23)	45.07%	47.52%	0.10 (0.00)	2.61%	2.67%	£40.19 (0.57)	35.29%	37.15%
	Nov2007-Oct2009	0.20 (0.00)	2.91%	3.43%	£0.02 (0.00)	0.04%	0.06%	5.23 (0.03)	68.89%	72.64%	£21.39 (0.12)	35.07%	45.73%	1.78 (0.02)	19.80%	20.80%	£37.30 (0.35)	35.69%	46.67%	0.03 (0.00)	0.25%	0.26%	£5.29 (0.10)	3.31%	4.34%
	Nov2009-Oct2011	0.33 (0.00)	3.49%	4.45%	£0.03 (0.00)	0.06%	0.08%	8.27 (0.05)	72.98%	79.80%	£31.39 (0.20)	41.90%	56.56%	1.51 (0.01)	10.84%	11.82%	£28.38 (0.27)	27.02%	36.64%	0.01 (0.00)	0.06%	0.07%	£2.28 (0.04)	1.61%	2.23%
	Total	0.19 (0.00)	2.43%	2.83%	£0.02 (0.00)	0.02%	0.03%	4.74 (0.08)	62.17%	67.61%	£18.45 (0.31)	22.43%	31.51%	1.38 (0.01)	26.78%	28.34%	£30.81 (0.28)	37.12%	48.24%	0.04 (0.00)	1.35%	1.40%	£14.91 (0.47)	18.03%	20.22%
Dark																									
	Nov2005-Oct2007	0.00 (0.00)	0.15%	4.08%	£0.00 (0.00)	0.00%	0.10%	0.06 (0.00)	2.92%	66.59%	£0.22 (0.01)	0.69%	17.19%	0.02 (0.00)	1.31%	17.67%	£0.59 (0.02)	1.68%	20.17%	0.00 (0.00)	0.13%	10.96%	£5.19 (0.09)	5.77%	61.85%
	Nov2007-Oct2009	0.03 (0.00)	0.48%	5.17%	£0.00 (0.00)	0.01%	0.02%	0.39 (0.01)	6.27%	69.63%	£1.35 (0.02)	3.45%	11.49%	0.09 (0.00)	1.15%	17.97%	£1.99 (0.03)	3.23%	15.04%	0.02 (0.00)	0.26%	7.21%	£20.19 (0.22)	19.20%	73.44%
	Nov2009-Oct2011	0.07 (0.00)	0.79%	5.09%	£0.01 (0.00)	0.02%	0.04%	0.98 (0.01)	10.10%	76.69%	£3.31 (0.04)	6.11%	19.59%	0.20 (0.00)	1.57%	16.16%	£4.04 (0.05)	4.82%	19.76%	0.02 (0.00)	0.16%	2.05%	£19.02 (0.20)	18.46%	60.59%
	Total	0.03 (0.00)	0.38%	4.94%	£0.00 (0.00)	0.00%	0.01%	0.49 (0.01)	5.50%	73.61%	£1.65 (0.04)	2.01%	7.74%	0.10 (0.00)	1.21%	18.29%	£2.14 (0.05)	2.61%	10.99%	0.01 (0.00)	0.19%	3.15%	£14.95 (0.28)	17.77%	81.26%
Lit + Dark																							£0.00		
	Nov2005-Oct2007	0.05 (0.00)			£0.00 (0.00)			1.32 (0.00)			£5.70 (0.02)			1.23 (0.01)			£35.38 (0.23)			0.10 (0.00)			£45.38 (0.60)		
	Nov2007-Oct2009	0.23 (0.00)			£0.02 (0.00)			5.62 (0.03)			£22.74 (0.12)			1.86 (0.02)			£39.28 (0.36)			0.04 (0.00)			£25.48 (0.28)		
	Nov2009-Oct2011	0.39 (0.00)			£0.04 (0.00)			9.25 (0.05)			£34.70 (0.22)			1.70 (0.01)			£32.42 (0.29)			0.03 (0.00)			£21.30 (0.22)		
	Total	0.22 (0.00)			£0.02 (0.00)			5.22 (0.09)			£20.09 (0.34)			1.48 (0.01)			£32.95 (0.27)			0.05 (0.00)			£29.86 (0.40)		

In lit markets SORT is used to break up large orders into smaller pieces in order to allow for execution at the best possible price level across several venues. Breaking up large orders also has the advantage of concealing your intentions from the market in order to prevent front-running or other gaming activities that can result in higher transaction costs. Therefore, on the lit market it is understandable that average transaction sizes should decrease while the number of transactions increase.

The dark order market, however, is intended to be used by investors wishing to maintain the anonymity of their trading intentions by concealing from the market the existence of a large buy or sell order. Therefore, large orders do not necessarily need to be broken up for the purposes of concealment as this is the primary purpose of executing trades in the dark. In fact, if participants in dark trading venues allow their orders to be broken up into very small pieces they open themselves up to predatory algorithms who are more likely to detect the existence of large orders when they allow for small partial trade executions; algorithms are unlikely to risk placing large orders solely for detection purposes.

Average dark transaction sizes could, however, be decreasing due to decreasing probability of execution of large orders resulting from increased dark order market fragmentation. With investors spread across multiple dark trading venues the probability of finding a counterparty to a trade decreases.

8.0 Methodology

The following section contains information on the variables used in the study as well as how the variables were applied in order to test our hypotheses.

8.1 Dependent Variables

In line with previous research on the market quality implications of the increased use of dark liquidity (Buti, Rindi, and Werner, 2011, Degryse, de Jong, and van Kervel, 2011, and Gresse, 2012) we measure the impact of dark fragmentation on market quality by investigating the following dependent variables:

1. Depth-X(Depth(X))
2. Price Impact (PrI)
3. Effective Spread (EfS)
4. Realised Spread (RlZ)
5. Quoted Spread (QS)
6. Quoted Depth (QD)

Depth(X), quoted depth, and quoted spread measures will be calculated every second of the trading day compared previous studies where it is calculated every minute (Degryse, de Jong, and van Kervel , 2011). Forward looking transaction measures such as price impact and realised spread will compare the quoted spread midpoint immediately before the transaction with the midpoint one second after the transaction has been executed. The 1-second time span is used as recommended by Henker and Wang (2006) who argue that even a 5-second window is too large, which raises concerns over the validity of the 1 and 5-minute windows used in previous studies (Degryse, de Jong, and Van Kervel , 2011, Gresse 2012).

Specifications on how the measures are calculated are as follows:

1. **Depth(X)$_{i,t}$** –[50] The average daily (t) value of the shares offered by a company (i) within a fixed interval, X, around the midpoint, measured in British Pound Sterling (£). It is used to determine how deep into the order book the hypothesised effects are felt. It is calculated as follows:

   i. $\text{DepthAsk(X)}_{i,t,s} = \sum {Q_{i,t,s}}^{Ask} \; x \; {P_{i,t,s}}^{Ask} \; where \; {P_{i,t,s}}^{Ask} < M_{i,t,s} \; x \; (1 + X)$ (1)

   Where i represents a particular company,

   t is the observation day,

   s is the second/time of day t.

   ${Q_{i,t,s}}^{Ask}$ is the number of shares available at a particular ask price,

   ${P_{i,t,s}}^{Ask}$ is the ask price,

   $M_{i,t,s}$is the midpoint of the best bid/ask spread,

   X is the number of basis points around the midpoint.

   ii. $\text{DepthBid(X)}_{i,t,s} = \sum {Q_{i,t,s}}^{Bid} \; x \; {P_{i,t,s}}^{Bid} \; where \; {P_{i,t,s}}^{Bid} > M_{i,t,s} x \; (1 - X)$ (2)

   Where i represents a particular company,

   t is the observation day,

   s is the second/time of day t.

   ${Q_{i,t,s}}^{Bid}$ is the number of shares available at a particular bid price,

   ${P_{i,t,s}}^{Bid}$ is the bid price.

   $M_{i,t,s}$is the midpoint of the best bid/ask spread,

   X is the number of basis points around the midpoint.

[50] Depth(X) was first introduced by Degryse, de Jong, and van Kervel (2011).

iii. $Depth(X)_{i,t,s} = DepthBid(X)_{i,t,s} + DepthAsk(X)_{i,t,s}$ (3)

Using a simple average we then calculate the average daily depth for each company, $Depth(X)_{i,t}$.

We use this measure to test the effects on depth deep within the order book as changes observed solely at the best price level are not always indicative of effects throughout the order book. It is used to test all three of our hypotheses.

2. **Price Impact$_{i,t}$ (PrI)** - Price impact used to test the information content of trades. It is based on executed transactions and is calculated as follows:

i. $$PrI_{i,t,z} = \frac{M_{i,t,z} - Mi_{i,t+X,z}}{M_{i,t,z}} \quad (4)$$

Where i represents a particular company,

t is the observation day,

z is a transaction identifier,

$M_{i,t,z}$ is the midpoint of the best bid/ask spread for company i on day t immediately before transaction z.

$Mi_{i,t+X,z}$is the midpoint of the best bid/ask spread for company i on day t X seconds after the execution of transaction z.

For each day we use a weighted average to determine the average price impact of a transaction. Each price impact measure is weighted by the size, in British Pound Sterling (£), of the transaction so that larger transaction are more influential than smaller ones.

We use this measure to test part of hypotheses 2 and 3 regarding the information content of trades.

3. **Effective Spread$_{i,t}$ (EfS)** - The effective spread captures the cost of a round-trip order by including both price movement (dealers coming in to execute orders at a better price than previously quoted) and market impact (spread widening due to the size of the order itself). It is based on executed transactions and is calculated as follows:

i. $$EfS_{i,t,z} = \frac{2\,x\,(P_{i,t,z} - M_{i,t,z})}{M_{i,t,z}} \quad (5)$$

Where i represents a particular company,

t is the observation day,

z is a transaction identifier,

$P_{i,t,z}$ is the price at which the transaction z occurred for company i on day t.

$M_{i,t,z}$ is the midpoint of the best bid/ask spread for company i on day t immediately before transaction z.

For each day we use a weighted average to determine the average effective spread of a transaction. Each effective spread measure is weighted by the size, in British Pound Sterling (£), of the transaction so that larger transaction are more influential than smaller ones.

We use this measure to test the part of hypothesis 1 that pertains to transaction costs.

4. **Realised Spread$_{i,t}$ (RlZ)** - The realised spread measures the extent to which a market centre provides liquidity in a volatile or fast moving market and also measures the extent of informed order flow. Informed orders are those submitted by persons with better information than is generally available in the market, which presents more of a risk to the liquidity provider on the other side of the trade. It is based on executed transactions and is calculated as follows:

i. $$RlZ_{i,t,z} = \frac{2\,x\,(P_{i,t,z} - Mi_{i,t+X,z})}{M_{i,t,z}} \quad (6)$$

Where i represents a particular company,

t is the observation day,

z is a transaction identifier,

P is the price at which the transaction z occurred for company i on day t,

$M_{i,t,z}$ is the midpoint of the best bid/ask spread for company i on day t immediately before transaction z.

$Mi_{i,t+X,z}$ is the midpoint of the best bid/ask spread for company i on day t X seconds after the execution of transaction z.

For each day we use a weighted average to determine the average realised spread of a transaction. Each realised spread measure is weighted by the size, in British Pound Sterling (£), of the transaction so that larger transaction are more influential than smaller ones.

We use this measure to test the part of hypothesis 1 that pertains to transaction costs.

5. **Quoted Spread (QS)$_{i,t}$** - The quoted spread measures the difference between the best bid and best ask with respect to the midpoint. It is calculated as follows:

i. $$QS_{i,t,s} = \frac{{P_{i,t,s}}^{BestAsk} - {P_{i,t,s}}^{BestBid}}{M_{i,t,s}} \quad (7)$$

Where i represents a particular company,

t is the observation day,

s is the second/time of day t.

${P_{i,t,s}}^{BestAsk}$ is the best available ask price,

${P_{i,t,s}}^{BestBid}$ is the best available bid price.

For each day we use a weighted average to determine the average quoted spread of throughout the day. Each quoted spread measure is weighted by the quoted depth, in British Pound Sterling (£), so that spreads with a large number of stocks available at the bed bid/ask are more influential than those than may only contains a few shares.

We use this measure to test a portion of all 3 hypothesis as spreads are a standard market quality measure.

6. **Quoted Depth (QD)$_{i,t}$** - The quoted depth measures the value of stocks within the best bid and ask quotes, in British Pound Sterling (£). It is calculated as follows:

i. $$QD_{i,t,s} = {P_{i,t,s}}^{BestAsk} x\ {Q_{i,t,s}}^{BestAsk} + {P_{i,t,s}}^{BestBid} x\ {Q_{i,t,s}}^{BestBid} \quad (8)$$

Where i represents a particular company,

t is the observation day,

s is the second/time of day t,

${P_{i,t,s}}^{BestAsk}$ is the best available ask price,

${P_{i,t,s}}^{BestBid}$ is the best available bid price,

${Q_{i,t,s}}^{BestAsk}$ is the number of stocks available at the best ask price,

$Q_{i,t,s}$ is the number of stocks available as the best bid price.

Using a simple average we then calculate the average daily quoted depth for each company, $QD_{i,t}$.

We use this measure to test the effects on depth at the best price level. It is primarily used to test our first hypothesis but we refer to quoted depth throughout the study.

All transactions and quotes residing outside of the UK will be converted into British Pound Sterling (£) at the closing exchange rate for the day in question.

8.2 Independent variables

This following section lists the series of independent variables used in the study, some of which are regressors while the remainder are control variables.

The aforementioned dependent measures are regressed against the following independent variables:

1. Lit Fragmentation (LF)
2. Dark fragmentation (DF)
3. Dark Volume (DV)
4. Dark Proportion [Market Share] (DP)
5. Market Capitalisation (MC)
6. Price (PR)
7. Volatility (σ)
8. Total volume (Vol).

8.2.1 Regressors

The independent regressors are calculated as follows:

1. **Lit Fragmentation (LF)** $_{i,t}$ – This is the extent of fragmentation in the lit market and it is measured by 1-Herfindhal-Hirschman Index(HHI). This variable will be used to test hypothesis 1. It is calculated as follows:

   i. $$LF_{i,t} = 1 - HHI_{i,t} = 1 - \sum_{v=1}^{n} MS_{i,t,v}^2 \quad (9)$$

   Where i represents a particular company,

   t is the observation day,

   v represents a particular visible liquidity venue,

   MS_v^2 is the squared market share of lit trading venue v, measured by the number of stocks traded in venue v when compared to the lit market as a whole.

1- HHI is used in order to more easily visualize a relationship between lit order book fragmentation and the pre-defined liquidity measures. A positive coefficient would indicate that increased fragmentation, as conveyed by an increase in LF, leads to an increase in the dependent measures.

2. **Dark Volume (DV)** $_{i,t}$ **–** This variable indicates the popularity of dark trading and is measured by the proportion of trades/dark liquidity market share, in British Pound Sterling (£), that results from transactions in a dark order book market. This variable is used to test hypothesis 2.

3. **Dark Proportion (DP)**$_{i,t}$ **–** This is the market share of the dark order book market. It is calculated as follows:

   i. $DP_{i,t} = DV_{i,t} / Vol_{i,t}$ (10)

   Where i represents a particular company,

   t is the observation day,

   $DV_{i,t}$ is the daily transaction volume, in British Pound Sterling (£), of the dark order book market,

   $Vol_{i,t}$ is the total daily volume for the firm, in British Pound Sterling (£). This variable is used to compliment the dark volume measure as it will inform us whether the increased volume in the dark market is a result of increased total volume[51] or trade migrations from the lit to the dark market.[52]

4. **Dark Fragmentation (DF)** $_{i,t}$ – This is the extent of fragmentation in the dark market and it is measured as 1 – HHI where HHI is the Herfindhal-Hirschman Index. It is calculated as follows:

   ii. $DF_{i,t} = 1 - HHI_{i,t} = 1 - \sum_{v=1}^{n} MS_{i,t,v}^2$ (11)

   Where i represents a particular company,

   t is the observation day,

   v represents a particular dark liquidity venue,

   MS_v^2 is the squared market share of dark trading venue v, measured by the number of stocks traded in venue v when compared to the dark market as a whole.

[51] The increase in dark volume could be a direct result of an increase in total trading activity for the day.

[52] As an increase in dark volume coupled with an increase in the proportion of dark trading implies that subsequent effects are as a result of trades favouring execution in the dark market over the lit market.

1- HHI is used in order to more easily visualize a relationship between dark order book fragmentation and the pre-defined liquidity measures. A positive coefficient would indicate that increased fragmentation, as conveyed by an increase in LF, leads to an increase in the dependent measures.

This variable will be used to test hypothesis 3.

8.2.1.1 Dark Fragmentation

Dark fragmentation takes into consideration the fragmentation timeline introduced in Section 7.4. As order books consolidate we merge the results of their market share into a single figure, thereby effectively reducing the total number of distinct dark trading venues.

Unlike previous studies we construct a Herfindahl-Hirschman Index (HHI) for dark trading venues in order to determine the level of fragmentation in the dark market, as opposed to solely relying on dark volume or dark market share. As indicated by Figure 1, approximately 51% of dark liquidity transactions can be explicitly attributed to a trading venue, while the remaining 49% are attributed to a pool of 30+ dark liquidity providers.

For the venues whose trades we cannot explicitly identify, we group the liquidity providers into one of two categories, major and minor contributors. Major contributors will be assigned twice the market share of minor contributors and will consist of the founding nine members of BOAT, a trade reporting facility later acquired by Markit.

For example, if the pool of attributable trades is comprised of ten dark liquidity providers, of which five were major contributors and five were minor contributors, for the purpose of our index calculation major contributors are given a market share of 2/15 while minor contributors are given a market share of 1/15. This method, while far from exact, is an improvement over discarding dark venue level data because half of the transactions volume cannot be attributed to a particular liquidity provider.

The founding nine BOAT members are chosen as major contributors as they consist of established banks, investments funds, and crossing networks whose annual activities far exceed, in terms of revenues, those of the remaining members.

We initially use two separate measures of dark fragmentation, one that includes the effect of implicit consolidation and one that does not, in order to test hypothesis 3. This is done as the two measures reveal different information about the status of the dark order book market; the measure that does not include implicit consolidation better reflects that stated status of fragmentation in the dark order book as is observed through reporting data while the measure that includes implicit

consolidation is more reflective of the true state of fragmentation in the dark order book market as it considers the effects of liquidity sharing amongst dark liquidity providers.

Before running regressions using our dark fragmentation we first check to see whether it is necessary to run regressions on each measure individually. In other words we test to see whether the unconsolidated and consolidated measures contain unique information within themselves. Table 4 displays correlation information among the independent regressors. We observe that unconsolidated and consolidate dark fragmentation have a correlation coefficient of 0.995. This indicates that, while the measures are different as indicated in Figure 6, they effectively explain the same factor, dark fragmentation.

Table (4) Independent Variable Correlations

The table shows the correlation coefficients among between independent variables used in the study. The variables can be segregated into two groups: Independent regressors (Lit Fragmentation, Dark Fragmentation, Dark Fragmentation [unconsolidated], Dark Volume, and Dark Proportion/Market Share) and control variables (Market Capitalisation, Price, Volatility [standard deviation], and Total Volume)

	LIT_FRAGMENTATION	DARK_FRAGMENTATION	DARK_FRAGMENTATION_UNC	LN_DARK_VOLUME	PROPORTION_DARK	LN_MARKETCAP	LN_PRICE	LN_SD	LN_TOTAL_VOLUME
LIT_FRAGMENTATION	1								
DARK_FRAGMENTATION	.627**	1							
DARK_FRAGMENTATION_UNC	.640**	.995**	1						
LN_DARK_VOLUME	.474**	.490**	.508**	1					
PROPORTION_DARK	.492**	.530**	.558**	.730**	1				
LN_MARKETCAP	.020**	.009*	.007	.373**	.008*	1			
LN_PRICE	.012**	-.084**	-0.085	.102**	-.077**	.480**	1		
LN_SD	.249**	.206**	.208**	.194**	.112**	-.007	.032**	1	
LN_TOTAL_VOLUME	.025**	.075**	.082**	.580**	.170**	.432**	.319**	.140**	1

As the two measures of consolidation are very similar, statistically, we will use the consolidated form on dark fragmentation, the measure that takes into considering liquidity sharing, in all future regressions as it is a truer representation of the state of fragmentation in the market in that it takes more factor (e.g. liquidity sharing) into consideration.

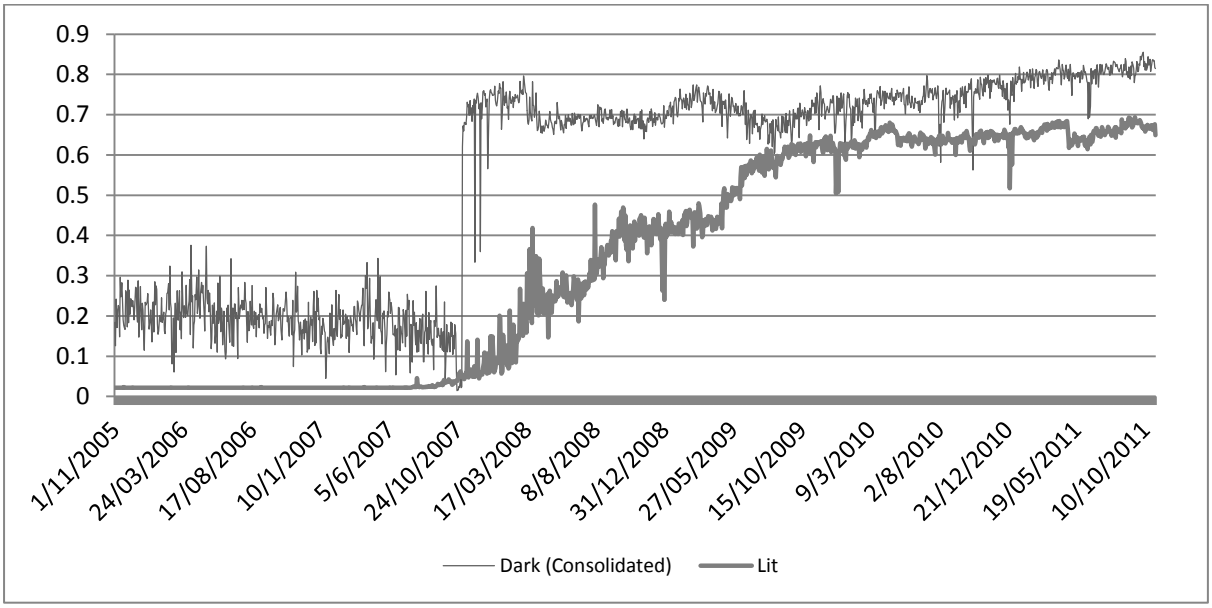


Figure (6) Market Fragmentation in Lit and Dark Liquidity Markets for all FTSE-100 stocks

The figure shows that average daily level of fragmentation per company in both lit and dark liquidity markets as measured by the (1- Herfindahl-Hirschman Index). The figure presents levels of fragmentation both with and without the effects of implicit consolidation through liquidity sharing for dark order markets. Values close to 0 indicate that the market is highly concentrated while values close to 1 indicate that the market is highly fragmented, with 0 indicating perfect consolidations while 1 indicating perfect fragmentation. The labels in the legend appear vertically in the same order as the lines in the graph. That is, lit order book fragmentation is the bottom line while unconsolidated dark order book fragmentation is the top line.

8.2.2 Control variables

The following is a list of the control variables used in the study:

1. **Volatility $(\sigma)_{i,t}$** - The volatility of a stock will be measured by the standard deviation of stock returns over the course of a trading day. It is calculated as follows:

   i. $$r_{i,t,s} = Ln(\frac{Mi_{,t,s}}{M_{i,t-1,s}}) \quad (12)$$

   Where i represents a particular company,

   t is the observation day,

   s is the second/time of day t,

   $r_{i,t,s}$ is the logarithmic return between 1 second snapshots,

   $Mi_{,t,s}$ is the current midpoint of the best bid-ask spread,

$M_{i,t-1}, s$ is the midpoint of the best bid/ask spread from the previous second.

ii. $\overline{r_{i,t}} = \frac{\sum_{s=1}^{S} r_{i,t,s}}{S}$ (13)

Where i represents a particular company,

t is the observation day,

s is the second/time of day t,

$r_{i,t,s}$is the logarithmic return between 1 second snapshots,

$\overline{r_{i,t}}$ is the average return over the course of the trading day,

S is the number of seconds over the course of the trading day.

iii. $\sigma_{i,t} = \sqrt{\frac{\sum_{s=1}^{S}(r_{i,t,s} - \overline{r_{i,t}})^2}{S-1}}$ [53] (14)

Where i represents a particular company,

t is the observation day,

s is the second/time of day t,

$r_{i,t,s}$is the logarithmic return between 1 second snapshots,

$\overline{r_{i,t}}$ is the average return over the course of the trading day,

S is the number of seconds over the course of the trading day.

2. **Price $(Pr)_{i,t}$** – Price is the daily value weighted average price, measured in British Pound Sterling(£).

3. **Market Capitalisation $(MC)_{i,t}$ -** Market capitalisation is the size of the company and is calculated as follows:

   i. $MC_{i,t} = Pr_{i,t} * NumSh_{i,t}$ (15)

   Where $NumSh_{i,t}$ is the total number of shares outstanding.[54]

4. **Total Volume $(Vol)_{i,t}$** – Total volume is the total trading volume of stock over the course of a single trading day, measured in British Pound Sterling(£). [55]

[53] We are using T-1 as this is a sample measure because it is not possible to have all possible outcomes.
[54] To determine how many shares a company has outstanding at any given point in time we used the figures as presented in quarterly reports.

8.3 Panel Regression

We utilize a panel regression to analyse our data. This type of regression is appropriate as the data consists of multiple entities (stocks) that are observed over more than two points in time. A time series analysis would not be appropriate here as the data consists of multiple entities (stocks). Also, a cross sectional regression would not be appropriate as the data consists of observations over multiple time periods.

The base for the regression formula is:

$$L_{i,t} = b_0 + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DP_{i,t} + b_4 DF_{i,t} + b_5 \sigma_{i,t} + b_6 lnPr_{i,t} + b_7 lnMC_{i,t} + b_8 lnVol_{i,t} + \mu_{i,t} \quad (16)$$

The regression model is extended to include the entity and time fixed effects as outlined in the following sections, Sections 8.3.1 and 8.3.2, respectively. The extended model is:

$$L_{i,t} = \alpha_i + \gamma_t + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DF_{i,t} + b_4 DP_{i,t} + b_5 lnPr_{i,t} + b_6 lnMC_{i,t} + b_7 lnVol_{i,t} + b_8 \sigma_{i,t} + \mu_{i,t} \quad (17)$$

Time and entity fixed effects are included in the model in order to reduce the effects of omitted variable bias. This occurs when the omitted variable is either correlated with a regressor used in the model or when it is a determinant of the dependent variables, the liquidity measure. If these effects are not included our model will attribute a higher effect of the regressors to the dependent variable than actually exists, resulting in a model that does not measure the true effect of the regressors on the dependent variable.

To determine the effectiveness of our regressors we perform an ordinary least squares (OLS) regression on the data and assess the significance of the regressors.

8.3.1 Entity Fixed Effects

It is important that the model controls for omitted variables in the panel data when the omitted variables vary across entities but do not change over time. These include factors such as the industry in which the company operates as well as its organisational structure. To account for this effect we add to the model a set of binary dummy variables, D_2, D_3.. D_n , where D_i is a fixed effect binary dummy variable for stock i that does not change over time. This results in the following regression model:

$$L_{i,t} = b_0 + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DP_{i,t} + b_4 DF_{i,t} + b_5 \sigma_{i,t} + b_6 lnPr_{i,t} + b_7 lnMC_{i,t} + b_8 lnVol_{i,t} + b_9 D_2 + b_{10} D_3 + \cdots + b_{8+n-1} D_n + \mu_{i,t} \quad (18)$$

[55] For control variables 2-4 we will use the LN() of the original value. Logarithms convert changes in variables into percentage changes and this figure will provide a more descriptive result as it will scale down the changes amongst stocks.

where D_2, D_3.. D_n are the fixed effect binary dummy variables for stock i which are set to 1 when the data pertains to stock i, and 0 otherwise. The resulting model will consist of n intercepts, 1 for each observed entity (stock). This is formula that will be used in the regression; however, it can be summarized by the following model:

$$L_{i,t} = b_0 + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DP_{i,t} + b_4 DF_{i,t} + b_5 \sigma_{i,t} + b_6 lnPr_{i,t} + b_7 lnMC_{i,t} + b_8 lnVol_{i,t} + b_9 Z_i + \mu_{i,t} \quad (19)$$

Where Z_i is the unobserved variable which varies from stock to stock but remains fixed over time. This can be simplified to:

$$L_{i,t} = \alpha_i + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DP_{i,t} + b_4 DF_{i,t} + b_5 \sigma_{i,t} + b_6 lnPr_{i,t} + b_7 lnMC_{i,t} + b_8 lnVol_{i,t} + \mu_{i,t} \quad (20)$$

where $\alpha_i = b_0 + b_9 Z_i$

The former models, 18 and 19, define the change in the y-intercept with respect to the intercept of the first stock in the study[56], stock 1, while the latter models, 19 and 20, reorganize the inputs and define a unique intercept for each stock.

8.3.2 Time Fixed Effects

Just as entity fixed effects control for variables that are constant over time but differ across entities, time fixed effects control for variables that are constant across entities but change over time. This is particularly important over the observed period as effects resulting from events such as the Global Financial Crisis (GFC) are difficult to measure but, nonetheless, must be accounted for. To account for this effect we add to the model a set of binary dummy variables, S_2, S_3.. S_n , where S_t is a quarterly fixed effect binary dummy variable for time t that remains constant across entities but changes over time. This results in the following regression model:

$$L_{i,t} = b_0 + b_1 LF_{i,t} + b_2 DV_{i,t} + b_3 DP_{i,t} + b_4 DF_{i,t} + b_5 \sigma_{i,t} + b_6 lnPr_{i,t} + b_7 lnMC_{i,t} + b_8 lnVol_{i,t} + b_9 D_2 + b_{10} D_3 + \cdots + b_{8+n-1} D_n + b_{8+n} S_2 + b_{8+n+1} S_3 + \cdots + b_{8+n+T-2} S_n + \mu_{i,t} \quad (21)$$

where S_2, S_3.. S_n are the fixed effect binary dummy variable for time t which are set to 1 when the data pertains to time period t, and 0 otherwise. This model (21) is the starting point for our regression; however, it can be summarized by equation 17[57] where γ_t is the unobserved variable which varies over time but remains fixed for each stock.

[56] Note that there is no D_1 but only D_2.. D_n

[57] Note that there is no S_1 but only S_2— S_n.

8.3.3 Regression Assumptions

In order to draw valid conclusions from the results of the fixed effects panel regression the data must fulfil the following four assumptions: normality, linearity, homoscedasticity, and multicollinearity.

8.3.3.1 Normality

Linear regression assumes that the variables have normal distributions. Non-normally distributed data can distort relationships and significance tests. We run normality tests on both the individual variables as well as the resulting model itself.

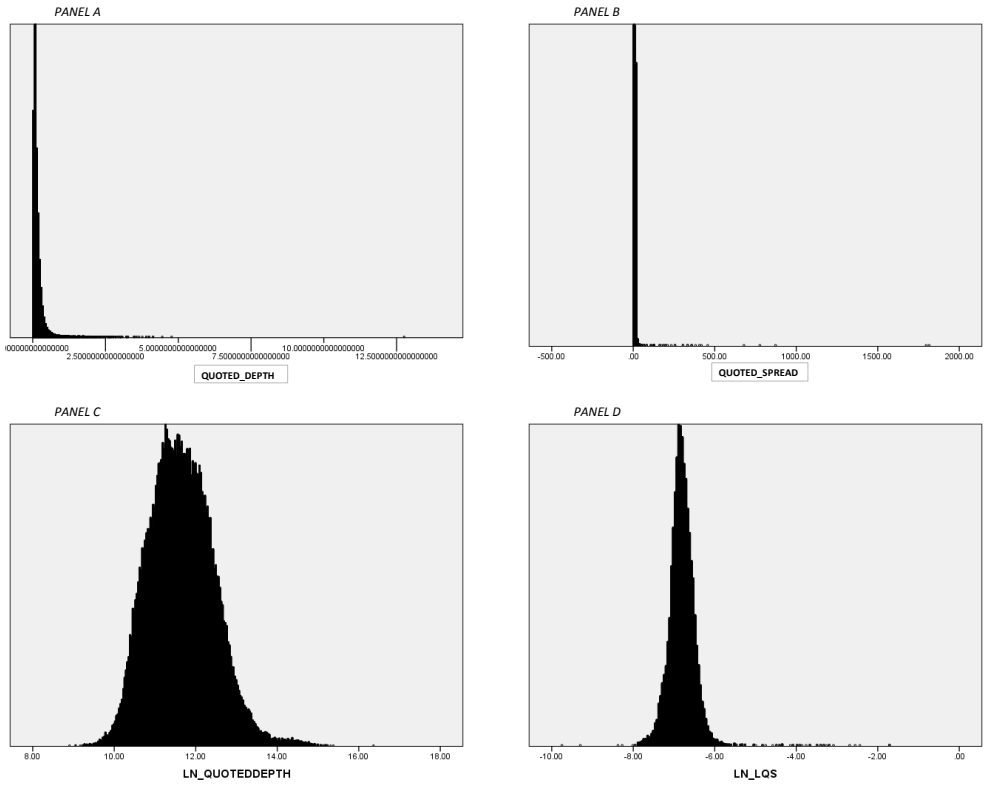


Figure (7) Distribution of Dependent Variables

The figure shows the distribution of the dependent variables local quoted depth and local quoted spread. Observed and transformed local quoted depth measures are found in Panels A and C, respectively. Observed and transformed local quoted spread measures are found in Panels B and D, respectively.

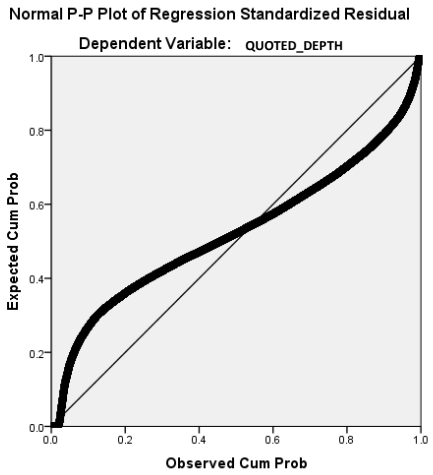
We begin by graphing observations for each independent and dependent variable and checking to see whether a normal distribution is present. We perform the test on all independent and dependent variables. Panels A and B of Figure 7 shows the distribution of the local quoted depth and local quoted spread measures, respectively; the remaining dependent variables were excluded due to the redundancy in the presented results. We clearly see that the dependent variables are heavily skewed to the right. In order to compensate for this we decide to transform all dependent

variables using the LN() function. The resulting distributions are displayed in Figure 7b and are clearly more normal. Similar results are found for all independent measures, with the exception of the fragmentation, LF and DF, and market share, DP, and as a result we transform all independent variables, excluding the aforementioned three variables, using the LN() function. Note that the three non-adjusted independent variables are all measured on scales from 0 to 1.

After performing the above transformations, and using local quoted depth as an example, we see the normal probability plot go from the bowed s-shaped curve in Panel A of Figure 8 to a roughly straight line in Panel B of Figure 8. Again this is consistent for all dependent measures and graphs have been excluded due to redundancy.

The tests outlined in this section indicate that our model meets the required normality assumption.

Panel A



Panel B

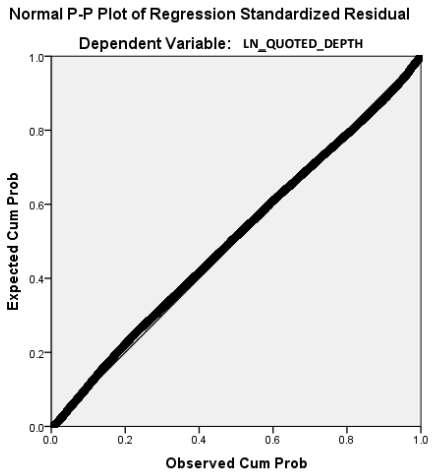


Figure (8) Normal Probability Plots

The figure shows the normal probability plots resulting from regression on local quoted depth. Panel A shows the plot prior to transforming independent and dependent variables while Panel B shows the plot after data transformations have been completed.

8.3.3.2 Linearity

When performing a linear regression we must also check to see that there is a linear relationship between independent and dependent variables. If this relationship does not exist then we are incorrectly using a linear model to describe a non-linear relationship and, as a result, do not have meaningful coefficients. We check for linearity by observing the relationship between the predicted value and standardised residuals and look for any signs of a non-horizontal distribution around the x axis.

Panels A and B of Figure 9 contain the standardised residual versus predicted value plots for both local quoted depth and local quote spread, respectively. Both plots indicate that the residuals are evenly distributed about the x-axis and that no curvilinear pattern can be seen amongst the residuals. As both plots adhere to the requirement of linearity we can be confident in our use of a linear model to explain the relationship between our independent and dependent variables.

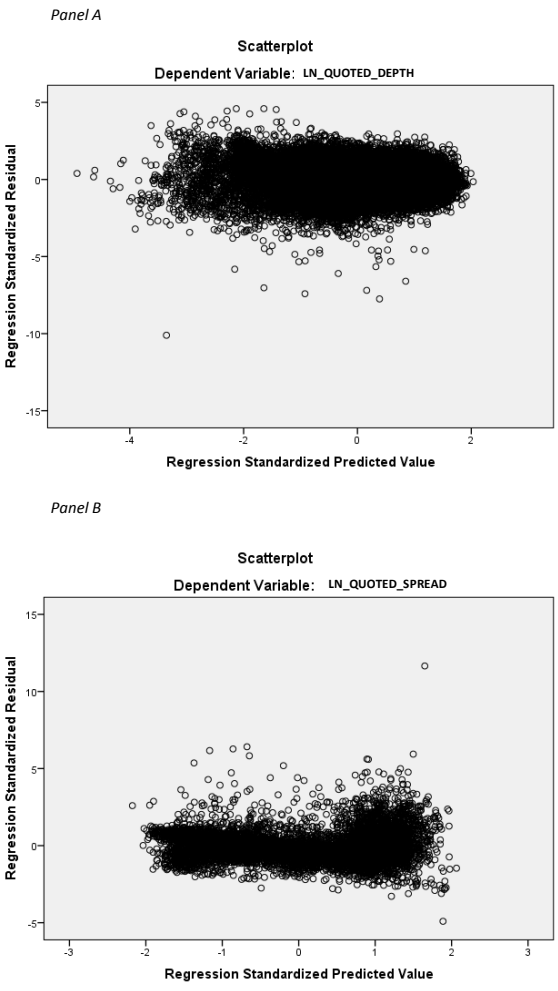


Figure (9) Standardised Residuals versus Predicted Values

This figure contains information on the relationship between standardised residuals and predicted values. Panel A contains information on local quoted depths while Panel B contains information on local quoted spreads.

8.3.3.3 Homoskedasticity

An error term is homoskedastic if the variance of the conditional distribution of the error term given the value of the dependent variable, var($\mu_{i,t}|X_i$ = x), is constant for i = 1…n, meaning it does not depend on x, or the predicted value resulting from the model. If a pattern can be found in the standardised residual versus predicted value plots the term is heteroskedastic, indicating that variance changes as we adjust our predicted value. We return to Panels A and B of Figure 9 to identify whether our model suffers from homoscedasticity. From both Panels A and B in Figure 9 we can see that the variance is constant regardless of the predicted value; it does not increase or decrease with increases in the predicted value nor does it display a bow-tie or diamond shape. As a result we can be confident in assuming that the model does not suffer from heteroskedasticity.

8.3.3.4 Multicollinearity

The final assumption is a test of for multicollinearity among the independent measures. We perform multiple tests to check for this condition.

We begin by inspecting the correlations among the independent variables to make sure none of our measures are redundant. Table 4 contains the correlation measures between all of our independent measures. We notice that to dark volume measure (LN_Dark_Volume) and the dark market share measure (Proportion_Dark) are highly correlated with each other, with a correlation coefficient of 0.73. This indicates that using both measures would be redundant and result in untrustworthy coefficients. We exclude dark volume from future regressions as the dark market share measure is much more revealing in terms of its information content. Due to its positive correlation with dark volume we know that dark market share increases with increases in the dark volume. But by keeping that market share measure we gain additional insight on the effects of trades migrating from the lit to the dark order book. Further inspection of Table 4 shows no other signs of significant multicollinearity. Oddly, this also pertains to the control variables of market capitalisation and price. It would be expected that these two variables would display high multicollinearity as the market cap measure utilizes the price in its calculations. But since there is no indicator of high multicollinearity here we do not need to be concerned with removing any of these measures. Also, as they are control variables and are not used in the interpretation side of our analysis their removal is also not critical.

When observing correlation coefficients between variables, however, we may not notice the effects of increased multicollinearity resulting from the use of a combination of variables. To test for this condition we perform a regression on our data where we regress one independent measure against the remaining independent measures and repeat this step until all independent variables have been used as the dependent value. In this test we look out for any noticeably large variance inflation factors (VIF) with values over 3 indicating some multicollinearity, values over 5 indicating significant

multicollinearity issues, and values over 10 indicating extremely high multicollinearity. Our main concern is the interaction among the 3 remaining key regressors: lit fragmentation, dark fragmentation, and dark proportion.

In Table 5, Panels A – D, we see the results of the aforementioned regressions. We only display the regression results that contain all 3 key regressors as independent variables as it is their interactions that we are most concerned with. In each table we notice that that VIF values are all below 3 which indicates low multicollinearity among our independent measures.

Table (5) Variance Inflation Factors Among Independent Variables

Table 5 contains information on the variance inflation factors among independent variables. Panels A – D display the values resulting from the removal of a different control variable (Market Capitalisation, Price, Volatility, and Total Volume) from the analysis. The control variable that was removed from the current iteration can be found below each panel.

Panel A

Model		Collinearity Statistics	
		Tolerance	VIF
1	LN_PRICE	.864	1.157
	LN_SD	.914	1.094
	LN_TOTAL_VOLUME	.834	1.200
	PROPORTION_DARK	.646	1.549
	HHI_DARK_CONSOLIDATED	.533	1.876
	HHI_LIT_UNCONSOLIDATED	.543	1.840

a. Dependent Variable: LN_MARKETCAP

Panel B

Model		Collinearity Statistics	
		Tolerance	VIF
1	LN_SD	.885	1.130
	LN_TOTAL_VOLUME	.408	2.453
	PROPORTION_DARK	.631	1.586
	HHI_DARK_CONSOLIDATED	.539	1.856
	HHI_LIT_UNCONSOLIDATED	.542	1.845
	LN_MARKETCAP	.430	2.323

a. Dependent Variable: LN_PRICE

Panel C

Model		Collinearity Statistics	
		Tolerance	VIF
1	LN_TOTAL_VOLUME	.430	2.328
	PROPORTION_DARK	.634	1.578
	HHI_DARK_CONSOLIDATED	.536	1.866
	HHI_LIT_UNCONSOLIDATED	.558	1.793
	LN_MARKETCAP	.387	2.582
	LN_PRICE	.753	1.328

a. Dependent Variable: LN_SD

Panel D

Model		Collinearity Statistics	
		Tolerance	VIF
1	PROPORTION_DARK	.673	1.486
	HHI_DARK_CONSOLIDATED	.533	1.876
	HHI_LIT_UNCONSOLIDATED	.552	1.811
	LN_MARKETCAP	.765	1.306
	LN_PRICE	.751	1.331
	LN_SD	.931	1.075

a. Dependent Variable: LN_TOTAL_VOLUME

Since we have proven that there is no multicollinearity among our remaining independent measures we must also check to see that his is true for the model itself once dummy variables have been applied. Table 6, Panel A, displays a truncated table containing the results of our regression on local quoted depth; a truncated table is used due to the number of dummy variables in the model. While the dummy variables have high VIF values this does not cause concern as we will not be interpreting the coefficients for the dummy variables themselves; they are merely used as control variables. Market capitalisation and price, have high VIF values, 244 and 143, respectively, that reduce to 2.67 and 1.62, respectively, when the dummy variables are removed. Such high VIF values indicate that both market cap and price do a great job at explaining difference in results due to firm specific factors as they were uncorrelated with other independent variables, as indicated in Tables 4 and 5. Removing the firm specific fixed effects and keeping the market capitalisation measures, and vice versa, has little effect on the coefficients of our explanatory variables and only slightly reduces the R^2 of the model. Since the effect of using firm fixed effects versus market capitalisation and price versus both is minimal, combined with the fact that we would be interested in interpreting the control variables we decide to drop the firm specific fixed effects in favour of having control variables with interpretable coefficients.

The most critical indicator in Table 6 Panel A is the VIF value of 30.7 for lit fragmentation. Such a large value for the explanatory variable is troublesome as it prevents us from making any meaningful interpretation of this variable's coefficients. However, in our previous multicollinearity tests we find that lit fragmentation is not correlated with any of our other independent measures. As a result we decide to remove all time fixed effects from the model and find that VIF reduces to 1.857 according to Panel B of Table 6. This indicates that our lit fragmentation measure does a great job a capturing time fixed effects and the use of quarterly dummy variables would be redundant.

Table 6 Panel B contains the results of a regression on local quoted depth, as in Table 4 Panel A, however all fixed effects have been removed. The resulting model has not changed significantly in terms of the coefficients for our 3 key independent variables. While the magnitudes of the coefficients have increased slightly after removing the fixed effects the signs are all the same, meaning that we have not significantly affected the model by removing the dummy variables but have increased the interpretative capability of independent coefficients. The size of the coefficient for lit fragmentation, however, did increase noticeably in magnitude from -0.144 to -0.952 due to improvements in multicollinearity.

Table (6) Variance Inflation Factors for 'The Model'

Table 6 shows information on variance inflation factors resulting from running a regression on one of our dependent measures (Local Quoted Depth). Panel A contains the results from the original model before adjustments are made to handle multicollinearity. Note that some firm specific and time specific dummy variables have been hidden to help with the presentation of Panel A. Panel B contains the results of the same regression after we accommodate for multicollinearity.

PANEL A

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	6.390	.155		41.098	0.000		
	AntoFagasta_DUMMY	.196	.017	.035	11.545	.000	.365	2.743
	AssocBrFoods_DUMMY	.397	.019	.072	20.381	.000	.269	3.724
	AstraZeneca_DUMMY	.615	.015	.109	40.060	0.000	.457	2.188
	InterconHotelG_DUMMY	.508	.034	.093	15.136	.000	.090	11.162
	NationalGrid_DUMMY	1.077	.023	.195	46.122	0.000	.189	5.288
	Next_DUMMY	.382	.041	.070	9.296	.000	.060	16.654
	Pearson_DUMMY	.727	.019	.133	38.380	0.000	.282	3.543
	RDutchShellB_DUMMY	.607	.035	.108	17.462	.000	.088	11.410
	SevernTrent_DUMMY	.582	.039	.106	14.923	.000	.066	15.069
	Shire_DUMMY	.645	.024	.117	26.691	.000	.174	5.735
	SmithNephew_DUMMY	.767	.019	.140	41.116	0.000	.291	3.442
	SmithsGroup_DUMMY	.512	.028	.093	18.306	.000	.129	7.728
	Tesco_DUMMY	.454	.041	.082	11.208	.000	.064	15.722
	Wolseley_DUMMY	.575	.042	.105	13.552	.000	.056	17.807
	@2005_Q2	-.134	.010	-.034	-13.270	.000	.520	1.922
	@2008_Q2	-1.266	.017	-.323	-74.983	0.000	.182	5.499
	@2008_Q3	-1.148	.019	-.288	-60.981	0.000	.151	6.610
	@2008_Q4	-1.183	.020	-.298	-58.251	0.000	.129	7.760
	@2009_Q1	-1.045	.021	-.262	-50.064	0.000	.123	8.104
	@2009_Q2	-.859	.021	-.218	-40.142	0.000	.114	8.736
	@2009_Q3	-1.038	.021	-.258	-48.948	0.000	.122	8.230
	@2009_Q4	-.990	.021	-.249	-46.164	0.000	.116	8.609
	@2010_Q1	-.920	.022	-.230	-42.248	0.000	.114	8.788
	@2010_Q2	-.996	.022	-.240	-45.719	0.000	.122	8.178
	@2010_Q3	-1.073	.022	-.266	-49.585	0.000	.117	8.542
	@2010_Q4	-1.421	.022	-.355	-64.627	0.000	.112	8.955
	LN_MARKETCAP	.148	.021	.202	7.202	.000	.004	234.324
	LN_PRICE	.149	.021	.154	6.979	.000	.007	143.915
	LN_SD	-.094	.002	-.135	-51.167	0.000	.487	2.054
	LN_TOTAL_VOLUME	.147	.003	.178	44.274	0.000	.209	4.791
	LN_DARK_VOLUME	.022	.002	.058	13.817	.000	.190	5.258
	PROPORTION_DARK	-.300	.018	-.034	-9.829	.000	.274	3.656
	DARK_FRAGMENTATION	-.280	.008	.019	5.553	.000	.276	3.627
	LIT_FRAGMENTATION	-.144	.029	-.050	-4.960	.000	.033	30.700

a. Dependent Variable: LN_QUOTEDDEPTH

PANEL B

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	5.234	.050		105.560	0.000		
	LN_MARKETCAP	.228	.003	.312	73.871	0.000	.374	2.674
	LN_PRICE	-.084	.003	-.086	-29.025	.000	.751	1.332
	LN_SD	-.131	.002	-.188	-68.370	0.000	.882	1.133
	LN_TOTAL_VOLUME	.216	.003	.261	64.579	0.000	.407	2.455
	PROPORTION_DARK	-.420	.016	-.084	-25.865	.000	.629	1.591
	DARK_FRAGMENTATION	-.333	.008	-.140	-39.593	0.000	.533	1.877
	LIT_FRAGMENTATION	-.952	.010	-.333	-94.791	0.000	.538	1.857

a. Dependent Variable: LN_QUOTEDDEPTH

8.4 The Model

We use the following model for our analyses once we've corrected for all the deviations from the assumptions found in Section 8.3.3:

$$L_{i,t} = b_0 + b_1 LF_{i,t} + \ b_2 DP_{i,t} + \ b_3 DF_{i,t} + b_4 lnPr_{i,t} + b_5 lnMC_{i,t} + b_6 lnVol_{i,t} + \ b_7 \sigma_{i,t} + \mu_{i,t} \quad (22)$$

Where DF is the consolidated dark fragmentation measure.[58]

9.0 Results

According to our findings lit and dark order book fragmentation have opposing effects on market quality. Lit order book fragmentation is found to improve market quality while order migration from lit to dark order books and dark order book fragmentation predominantly have negative effects. According to the standardised coefficients for global and local order books, found in Panels A and B of Table 7, respectively, lit fragmentation has a large positive impact on market quality, increased dark market share has a large negative impact on market quality and dark fragmentation has a minor negative impact on market quality. Standardised coefficients are used in this situation as they are scaled against the remaining independent variables. As a result the size of the coefficient also tells us which variables have the greatest impact on the dependent measure and leads us to conclude that lit fragmentation has the greatest impact on market quality, with its effects being largely positive, while dark market share (proportion) has the greatest negative impact.

The remainder of this section contains information on the market quality implications of changes in our three forms of fragmentation: lit order book fragmentation, fragmentation between lit and ark order books, and dark order book fragmentation.

[58] The motivation behind selecting this consolidated form of the dark fragmentation measure can be found in Section 8.2.2.1.

Table (7) Global and Local Standardised Regression Results

The table contains information on the results of our regression analysis. Panel A contains Global order book data while Panel B contains local order book data. Quoted depth is measured as the value of stocks (£) at the best price level at the primary exchange (London Stock Exchange). Depth(X) is the value of stocks (£) at various distances, in basis points, from the local quoted depth. All depths were transformed with the Ln function due to the skewness of the data. Quoted spread, price impact, realised spread, and effective spread were measured in basis points prior to the Ln transformation required due to the skewness of the data. Market Cap, Price, SD, and Total Volume are the control variables. Dark volume is a measure of the total daily value (£) of dark order transactions. Proportion dark is the percentage of total orders executed in the dark. HHI Lit is the measure of lit order book fragmentation as measured by 1- 'Herfindahl-Hirschman Index'. HHI Dark (Consolidated) is the measure of dark order book fragmentation as measured by 1- 'Herfindahl-Hirschman Index' when implicit order book consolidation through liquidity sharing is considered, while HHI Dark (Unconsolidated) does not consider implicit consolidation. Coefficients are presented first with the corresponding T-stats presented in parenthesis below. ***, **, and * denote significance at the 1,5 and 10 percent levels, respectively.

Panel A: Global Order Book

	LN Quoted Depth	LN Depth10	LN Depth20	LN Depth30	LN Depth40	LN Depth50	LN Quoted Spread	LN Price Impact	LN Realised Spread	LN Effective Spread
All Companies										
Ln Market Cap	0.12 ***	0.26 ***	0.26 ***	0.24 ***	0.22 ***	0.20 ***	-0.20 ***	-0.12 ***	-0.16 ***	-0.20 ***
	(23.39)	(59.16)	(59.15)	(52.56)	(46.46)	(42.14)	(-21.02)	(-13.41)	(-19.03)	(-21.81)
Ln Price	-0.09 ***	0.02 ***	-0.03 ***	-0.04 ***	-0.04 ***	-0.04 ***	-0.01 *	0.05 ***	-0.02 ***	-0.01
	(-24.28)	(6.40)	(-10.81)	(-11.04)	(-11.83)	(-12.59)	(-1.94)	(7.66)	(-3.81)	(-1.14)
Ln SD	-0.46 ***	-0.45 ***	-0.48 ***	-0.49 ***	-0.49 ***	-0.49 ***	0.26 ***	0.48 ***	0.07 ***	0.14 ***
	(-132.35)	(-155.76)	(-165.61)	(-164.08)	(-160.76)	(-157.16)	(35.15)	(71.44)	(11.32)	(19.46)
Ln Total Volume	0.18 ***	0.30 ***	0.27 ***	0.26 ***	0.25 ***	0.24 ***	-0.23 ***	-0.14 ***	0.18 ***	0.20 ***
	(35.75)	(71.12)	(63.80)	(58.75)	(54.90)	(52.63)	(-23.29)	(-14.94)	(20.22)	(21.04)
Proportion Dark	-0.01 **	-0.04 ***	-0.03 ***	-0.03 ***	-0.03 ***	-0.03 ***	0.19 ***	0.11 ***	-0.07 ***	-0.09 ***
	(-2.55)	(-11.05)	(-8.81)	(-9.03)	(-8.14)	(-7.37)	(20.71)	(13.42)	(-8.21)	(-10.03)
Dark_Fragmentation	0.03 ***	-0.02 ***	0.00	-0.01 **	0.00	0.01 *	0.05 ***	0.13 ***	-0.10 ***	-0.10 ***
	(5.84)	(-5.34)	(-1.17)	(-2.23)	(-0.14)	(1.76)	(4.97)	(15.37)	(-11.93)	(-10.66)
Lit_Fragmentation	-0.01 **	0.29 ***	0.36 ***	0.37 ***	0.36 ***	0.34 ***	-0.49 ***	0.10 ***	-0.57 ***	-0.49 ***
	(-2.22)	(78.08)	(97.46)	(98.68)	(91.74)	(84.94)	(-53.29)	(12.04)	(-69.57)	(-55.37)
Adjusted R^2	0.260	0.481	0.484	0.460	0.430	0.406	0.337	0.435	0.475	0.391
#Observations	92803	92803	92803	92803	92803	92803	92803	92803	92803	92803
Upper Index Firms: Companies with Market Cap. > £10b										
Ln Market Cap	0.11 ***	0.23 ***	0.22 ***	0.20 ***	0.18 ***	0.18 ***	-0.37 ***	-0.21 ***	-0.19 ***	-0.21 ***
	(15.31)	(34.76)	(32.74)	(28.81)	(26.68)	(25.18)	(-33.39)	(-21.01)	(-19.29)	(-20.04)
Ln Price	-0.15 ***	-0.03 ***	-0.06 ***	-0.08 ***	-0.10 ***	-0.11 ***	-0.06 ***	0.06 ***	-0.08 ***	-0.07 ***
	(-27.76)	(-6.85)	(-12.28)	(-15.77)	(-18.41)	(-20.46)	(-5.73)	(6.01)	(-8.18)	(-7.04)
Ln SD	-0.44 ***	-0.50 ***	-0.50 ***	-0.50 ***	-0.49 ***	-0.48 ***	0.21 ***	0.51 ***	0.02 **	0.09 ***
	(-81.32)	(-103.52)	(-100.67)	(-98.46)	(-95.62)	(-93.25)	(21.98)	(58.27)	(2.56)	(9.59)
Ln Total Volume	0.06 ***	0.19 ***	0.15 ***	0.13 ***	0.12 ***	0.11 ***	-0.19 ***	-0.16 ***	0.14 ***	0.16 ***
	(8.67)	(29.97)	(23.91)	(20.48)	(18.12)	(16.86)	(-16.12)	(-14.32)	(13.51)	(14.25)
Proportion Dark	0.05 ***	0.06 ***	0.05 ***	0.05 ***	0.05 ***	0.05 ***	0.19 ***	0.15 ***	-0.10 ***	-0.13 ***
	(8.18)	(10.61)	(9.55)	(9.21)	(8.99)	(8.71)	(14.52)	(12.83)	(-8.16)	(-10.18)
Dark_Fragmentation	0.05 ***	0.05 ***	0.04 ***	0.03 ***	0.03 ***	0.04 ***	-0.02	0.08 ***	-0.09 ***	-0.10 ***
	(7.22)	(8.21)	(6.20)	(4.84)	(5.40)	(5.66)	(-1.22)	(6.56)	(-7.88)	(-8.16)
Lit_Fragmentation	-0.06 ***	0.20 ***	0.23 ***	0.22 ***	0.20 ***	0.18 ***	-0.49 ***	0.13 ***	-0.58 ***	-0.51 ***
	(-8.44)	(32.66)	(36.30)	(34.71)	(31.05)	(28.25)	(-38.10)	(11.21)	(-51.17)	(-41.95)
Adjusted R^2	0.247	0.397	0.370	0.343	0.323	0.308	0.372	0.485	0.505	0.437
#Observations	42024	42024	42024	42024	42024	42024	42024	42024	42024	42024
Lower Index Firms: Companies with Market Cap. < £10b										
Ln Market Cap	0.21 ***	0.31 ***	0.30 ***	0.29 ***	0.27 ***	0.26 ***	-0.14 ***	-0.15 ***	-0.04 ***	-0.08 ***
	(45.45)	(77.84)	(92.38)	(94.38)	(86.41)	(80.24)	(-12.03)	(-14.33)	(-3.44)	(-7.02)
Ln Price	0.05 ***	0.13 ***	0.04 ***	0.07 ***	0.08 ***	0.09 ***	0.09 ***	0.06 ***	0.08 ***	0.10 ***
	(13.28)	(36.55)	(15.76)	(25.26)	(29.45)	(32.39)	(7.95)	(6.38)	(8.64)	(9.45)
Ln SD	-0.41 ***	-0.34 ***	-0.39 ***	-0.39 ***	-0.40 ***	-0.40 ***	0.30 ***	0.43 ***	0.16 ***	0.21 ***
	(-93.42)	(-91.07)	(-130.08)	(-133.21)	(-134.58)	(-132.47)	(26.67)	(41.64)	(16.46)	(19.87)
Ln Total Volume	0.32 ***	0.34 ***	0.35 ***	0.34 ***	0.34 ***	0.34 ***	-0.24 ***	-0.11 ***	0.15 ***	0.16 ***
	(67.07)	(83.77)	(107.62)	(107.87)	(105.15)	(102.27)	(-20.63)	(-10.32)	(14.66)	(14.77)
Proportion Dark	-0.11 ***	-0.14 ***	-0.15 ***	-0.15 ***	-0.14 ***	-0.13 ***	0.23 ***	0.15 ***	-0.08 ***	-0.08 ***
	(-21.28)	(-32.61)	(-42.24)	(-43.76)	(-41.22)	(-38.40)	(16.96)	(11.72)	(-6.60)	(-6.46)
Dark_Fragmentation	-0.08 ***	-0.12 ***	-0.11 ***	-0.11 ***	-0.11 ***	-0.10 ***	0.09 ***	0.23 ***	-0.17 ***	-0.15 ***
	(-14.32)	(-23.55)	(-27.49)	(-30.02)	(-27.64)	(-24.06)	(6.48)	(17.26)	(-13.65)	(-11.16)
Lit_Fragmentation	0.07 ***	0.42 ***	0.64 ***	0.67 ***	0.67 ***	0.65 ***	-0.57 ***	0.01	-0.54 ***	-0.45 ***
	(12.99)	(89.53)	(171.84)	(186.97)	(182.09)	(172.09)	(-40.97)	(0.76)	(-44.85)	(-34.36)
Adjusted R^2	0.407	0.555	0.713	0.733	0.722	0.706	0.308	0.417	0.482	0.381
#Observations	50779	50779	50779	50779	50779	50779	50779	50779	50779	50779

Table 7 (continued)

Panel B: Local Order Book

	LN Quoted Depth	LN Depth10	LN Depth20	LN Depth30	LN Depth40	LN Depth50	LN Quoted Spread	LN Price Impact	LN Realised Spread	LN Effective Spread
All Companies										
Ln Market Cap	0.31 ***	0.45 ***	0.48 ***	0.46 ***	0.44 ***	0.42 ***	-0.18 ***	-0.14 ***	-0.19 ***	-0.23 ***
	(73.87)	(110.82)	(120.77)	(112.97)	(105.55)	(99.62)	(-17.65)	(-15.39)	(-20.95)	(-24.17)
Ln Price	-0.09 ***	0.01 ***	0.00 *	0.00	0.00	0.00	-0.03 ***	0.04 ***	-0.05 ***	-0.02 ***
	(-29.03)	(3.86)	(-1.77)	(-0.33)	(-0.69)	(-1.54)	(-3.75)	(6.19)	(-6.90)	(-3.34)
Ln SD	-0.19 ***	-0.17 ***	-0.20 ***	-0.24 ***	-0.26 ***	-0.27 ***	0.32 ***	0.45 ***	0.08 ***	0.08 ***
	(-68.37)	(-61.74)	(-79.55)	(-91.81)	(-95.98)	(-96.33)	(43.27)	(68.41)	(11.40)	(10.57)
Ln Total Volume	0.26 ***	0.33 ***	0.31 ***	0.30 ***	0.30 ***	0.30 ***	-0.29 ***	-0.13 ***	0.21 ***	0.23 ***
	(64.58)	(83.54)	(82.78)	(77.84)	(75.57)	(74.63)	(-28.35)	(-14.48)	(23.32)	(23.22)
Proportion Dark	-0.08 ***	-0.07 ***	-0.07 ***	-0.07 ***	-0.07 ***	-0.07 ***	0.19 ***	0.11 ***	-0.10 ***	-0.11 ***
	(-25.86)	(-22.62)	(-24.17)	(-22.77)	(-22.00)	(-22.21)	(19.93)	(13.10)	(-11.88)	(-12.62)
Dark_Fragmentation	-0.14 ***	-0.18 ***	-0.20 ***	-0.20 ***	-0.19 ***	-0.18 ***	0.01	0.12 ***	-0.13 ***	-0.12 ***
	(-39.59)	(-51.57)	(-59.76)	(-59.11)	(-54.69)	(-50.45)	(1.19)	(14.36)	(-14.41)	(-13.31)
Lit_Fragmentation	-0.33 ***	0.06 ***	0.17 ***	0.20 ***	0.19 ***	0.17 ***	-0.28 ***	0.16 ***	-0.51 ***	-0.42 ***
	(-94.79)	(17.72)	(53.13)	(59.25)	(54.26)	(48.30)	(-29.08)	(19.13)	(-59.58)	(-45.51)
Adjusted R^2	0.531	0.561	0.589	0.567	0.544	0.525	0.301	0.449	0.444	0.356
#Observations	92803	92803	92803	92803	92803	92803	92803	92803	92803	92803
Upper Index Firms: Companies with Market Cap. > £10b										
Ln Market Cap	0.23 ***	0.43 ***	0.43 ***	0.41 ***	0.39 ***	0.38 ***	-0.28 ***	-0.21 ***	-0.18 ***	-0.21 ***
	(37.49)	(71.33)	(67.96)	(62.36)	(59.07)	(56.54)	(-24.40)	(-21.18)	(-17.68)	(-19.59)
Ln Price	-0.27 ***	-0.09 ***	-0.12 ***	-0.15 ***	-0.17 ***	-0.19 ***	-0.05 ***	0.07 ***	-0.11 ***	-0.11 ***
	(-60.43)	(-20.33)	(-26.23)	(-29.71)	(-33.71)	(-37.57)	(-4.58)	(7.14)	(-10.56)	(-10.32)
Ln SD	-0.12 ***	-0.09 ***	-0.14 ***	-0.18 ***	-0.20 ***	-0.20 ***	0.33 ***	0.50 ***	0.04 ***	0.03 ***
	(-27.52)	(-20.00)	(-29.00)	(-37.81)	(-40.20)	(-40.31)	(32.19)	(57.07)	(4.36)	(2.86)
Ln Total Volume	0.19 ***	0.33 ***	0.29 ***	0.27 ***	0.25 ***	0.24 ***	-0.27 ***	-0.15 ***	0.15 ***	0.17 ***
	(33.42)	(57.30)	(47.30)	(42.48)	(39.67)	(37.96)	(-21.24)	(-14.20)	(13.33)	(14.20)
Proportion Dark	-0.08 ***	-0.04 ***	-0.04 ***	-0.03 ***	-0.03 ***	-0.03 ***	0.23 ***	0.17 ***	-0.12 ***	-0.15 ***
	(-15.26)	(-6.94)	(-6.76)	(-4.88)	(-4.58)	(-5.58)	(16.72)	(14.21)	(-9.46)	(-11.67)
Dark_Fragmentation	-0.17 ***	-0.21 ***	-0.24 ***	-0.25 ***	-0.24 ***	-0.23 ***	-0.06 ***	0.05 ***	-0.12 ***	-0.13 ***
	(-31.70)	(-39.10)	(-42.20)	(-42.44)	(-39.65)	(-37.69)	(-4.26)	(4.54)	(-9.61)	(-10.13)
Lit_Fragmentation	-0.37 ***	0.06 ***	0.15 ***	0.14 ***	0.11 ***	0.09 ***	-0.33 ***	0.17 ***	-0.52 ***	-0.44 ***
	(-65.87)	(9.94)	(25.40)	(23.76)	(18.61)	(14.98)	(-24.06)	(14.52)	(-43.84)	(-35.23)
Adjusted R^2	0.475	0.476	0.424	0.392	0.371	0.356	0.305	0.490	0.461	0.407
#Observations	42024	42024	42024	42024	42024	42024	42024	42024	42024	42024
Lower Index Firms: Companies with Market Cap. < £10b										
Ln Market Cap	0.20 ***	0.30 ***	0.34 ***	0.34 ***	0.32 ***	0.30 ***	-0.20 ***	-0.20 ***	-0.07 ***	-0.11 ***
	(50.99)	(72.84)	(88.94)	(90.50)	(84.52)	(79.86)	(-16.03)	(-18.53)	(-6.91)	(-9.29)
Ln Price	0.04 ***	0.07 ***	0.06 ***	0.08 ***	0.10 ***	0.11 ***	0.04 ***	0.02 **	0.07 ***	0.11 ***
	(13.29)	(19.04)	(17.97)	(25.84)	(29.73)	(33.08)	(3.24)	(2.07)	(6.87)	(10.24)
Ln SD	-0.35 ***	-0.41 ***	-0.45 ***	-0.45 ***	-0.47 ***	-0.47 ***	0.31 ***	0.38 ***	0.15 ***	0.16 ***
	(-96.77)	(-101.99)	(-125.22)	(-129.27)	(-132.80)	(-133.10)	(26.79)	(37.19)	(14.60)	(14.28)
Ln Total Volume	0.26 ***	0.33 ***	0.34 ***	0.33 ***	0.33 ***	0.33 ***	-0.28 ***	-0.11 ***	0.19 ***	0.20 ***
	(66.43)	(77.23)	(86.61)	(85.41)	(85.04)	(85.18)	(-22.76)	(-10.09)	(18.84)	(17.47)
Proportion Dark	-0.08 ***	-0.12 ***	-0.12 ***	-0.12 ***	-0.11 ***	-0.11 ***	0.22 ***	0.15 ***	-0.12 ***	-0.12 ***
	(-19.52)	(-26.01)	(-28.95)	(-28.73)	(-27.49)	(-26.50)	(15.31)	(11.88)	(-9.65)	(-8.86)
Dark_Fragmentation	-0.08 ***	-0.11 ***	-0.13 ***	-0.14 ***	-0.13 ***	-0.11 ***	0.09 ***	0.26 ***	-0.20 ***	-0.20 ***
	(-17.64)	(-21.17)	(-28.77)	(-29.59)	(-27.21)	(-23.95)	(5.93)	(19.92)	(-15.28)	(-14.05)
Lit_Fragmentation	-0.39 ***	0.04 ***	0.20 ***	0.24 ***	0.24 ***	0.22 ***	-0.30 ***	0.07 ***	-0.47 ***	-0.36 ***
	(-86.18)	(8.59)	(44.99)	(56.53)	(55.36)	(50.68)	(-20.68)	(5.97)	(-37.95)	(-26.62)
Adjusted R^2	0.586	0.507	0.601	0.613	0.608	0.600	0.253	0.445	0.461	0.348
#Observations	50779	50779	50779	50779	50779	50779	50779	50779	50779	50779

9.1 Lit Fragmentation

In this section we present our findings regarding the market quality implications of the fragmentation of orders within the lit order book market. We find that fragmentation in the lit order book market improves quality in the overall market, with the effects being greater, as indicated by a larger absolute coefficient, within the global visible order book compared to the local visible order book. As a result, lit order book fragmentation is beneficial to both institutional investors who can simultaneously access multiple markets using SORT and retail investors who do not have access to liquidity sourcing technology. However, the global order book experiences greater improvements as predicted in hypothesis 1.

Table 8, Panels A and B, contain the unstandardised coefficients for global and local order books, respectively. We refer to unstandardised coefficients as they are easier to interpret. However, we do also include standardised residuals in Table 7 in order to better gauge which independent measure has a greater impact on our dependent variables. Please note that all figures referenced from Table 8 are significant at the 1% level.

As indicated in Panels A and B of Table 8, we find that lit order book fragmentation has a significant effect on quoted spreads. Global order book spreads are more than halved, indicated by a coefficient of -0.55, when we move from a completely consolidated market with a lit fragmentation measure of 0 (i.e. 1 lit venue) to a completely fragmented market with a lit fragmentation measure of 1 (i.e. numerous competing lit venues). Another way that this can be stated is that for every increase in fragmentation of 0.01 global quoted spreads decrease by 0.55%. Local order book spreads decrease by 33% when we move from a perfectly consolidated to a perfectly fragmented market, as indicated in Table 5 Panel B. This supports hypothesis 1 in that we anticipate that the local order book will not be able to compete with the price savings of their newly formed competitors. The improved effects of competition are also observed by the decrease in both global and local realised and effective spreads. These findings contradict those made by Bennet and Wei (2006), Gajewski and Gresse (2007), Madhavan (1995), Easley, Kiefer, and O'Hara (1996), Bessembinder and Kaufman (1997), and Zhu (2012) but are consistent with studies across both upper and lower index firms and with theory presented by Degryse, de Jong, and van Kervel (2011), Gresse (2012), Fong, Madhavan, and Swan (2004), and Foucault and Menkveld (2008) who argue that both global and local spreads tighten with increased lit order book fragmentation, meaning that the local exchange is able to respond to increased competition by matching any price reductions available at competing venues.

A transition from perfect consolidation to perfect fragmentation reduces global realised and effective spreads by 128% and 93%, respectively, and local realised and effective spreads by 103% and 73%, respectively. This indicates an improvement in transaction costs which also supports our first hypothesis.

Global and local depth decreases at the best price level as indicated by their coefficients of –0.04 and -0.95, respectively. As expected, quoted depth was reduced by a larger extent in the local order book. This is to be expected as smaller liquidity suppliers are not able to match the rebate induced savings afforded to their larger, more competitive, counterparts. This also helps explain why depth decreases at the best price level but increases deeper within the order book. Panels A and B in Table 8 show that depth increases by 149% and 25% for global and local order books, respectively, when we include stocks offered at prices up to 10 basis points away from the midpoint of the best available bid/ask spread (Depth(10)). Therefore, while not all liquidity suppliers are

equally competitive, rebates and discounts allow for increased share offerings closer to the best price level.

Table (8) Global and Local Unstandardised Regression Results

The table contains information on the results of our regression analysis. Panel A contains Global order book data while Panel B contains local order book data. Quoted depth is measured as the value of stocks (£) at the best price level at the primary exchange (London Stock Exchange). Depth(X) is the value of stocks (£) at various distances, in basis points, from the local quoted depth. All depths were transformed with the Ln function due to the skewness of the data. Quoted spread, price impact, realised spread, and effective spread were measured in basis points prior to the Ln transformation required due to the skewness of the data. Market Cap, Price, SD, and Total Volume are the control variables. Dark volume is a measure of the total daily value (£) of dark order transactions. Proportion dark is the percentage of total orders executed in the dark. HHI Lit is the measure of lit order book fragmentation as measured by 1- 'Herfindahl-Hirschman Index'. HHI Dark (Consolidated) is the measure of dark order book fragmentation as measured by 1- 'Herfindahl-Hirschman Index' when implicit order book consolidation through liquidity sharing is considered, while HHI Dark (Unconsolidated) does not consider implicit consolidation. Coefficients are presented first with the corresponding T-stats presented in parenthesis below. ***, **, and * denote significance at the 1,5 and 10 percent levels, respectively.

Panel A: Global Order Book

	LN Quoted Depth	LN Depth10	LN Depth20	LN Depth30	LN Depth40	LN Depth50	LN Quoted Spread	LN Price Impact	LN Realised Spread	LN Effective Spread
All Companies										
Ln Market Cap	0.13 ***	0.35 ***	0.31 ***	0.27 ***	0.25 ***	0.22 ***	-0.08 ***	-0.07 ***	-0.13 ***	-0.14 ***
	(35.75)	(71.12)	(63.80)	(58.75)	(54.90)	(52.63)	(-23.29)	(-14.94)	(20.22)	(21.04)
Ln Price	-0.13 ***	0.04 ***	-0.05 ***	-0.05 ***	-0.06 ***	-0.06 ***	-0.01 *	0.03 ***	-0.02 ***	-0.01
	(-2.55)	(-11.05)	(-8.81)	(-9.03)	(-8.14)	(-7.37)	(20.71)	(13.42)	(-8.21)	(-10.03)
Ln SD	-0.53 ***	-0.66 ***	-0.61 ***	-0.60 ***	-0.60 ***	-0.59 ***	0.14 ***	0.39 ***	0.08 ***	0.13 ***
	(5.84)	(-5.34)	(-1.17)	(-2.23)	(-0.14)	(1.76)	(4.97)	(15.37)	(-11.93)	(-10.66)
Ln Total Volume	0.22 ***	0.45 ***	0.36 ***	0.33 ***	0.31 ***	0.30 ***	-0.08 ***	-0.07 ***	0.13 ***	0.12 ***
	(-2.22)	(78.08)	(97.46)	(98.68)	(91.74)	(84.94)	(-53.29)	(12.04)	(-69.57)	(-55.37)
Proportion Dark	-0.08 **	-0.34 ***	-0.24 ***	-0.25 ***	-0.23 ***	-0.21 ***	0.35 ***	0.31 ***	-0.25 ***	-0.28 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Dark_Fragmentation	0.09 ***	-0.09 ***	-0.02	-0.03 **	0.00	0.03 *	0.04 ***	0.19 ***	-0.19 ***	-0.15 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lit_Fragmentation	-0.04 **	1.49 ***	1.66 ***	1.68 ***	1.58 ***	1.47 ***	-0.55 ***	0.17 ***	-1.28 ***	-0.93 ***
	(0.37)	(0.55)	(0.49)	(0.47)	(0.46)	(0.45)	(0.47)	(1.07)	(1.25)	(1.32)
Adjusted R^2	0.260	0.481	0.484	0.460	0.430	0.406	0.337	0.435	0.475	0.391
#Observations	92803	92803	92803	92803	92803	92803	92803	92803	92803	92803
Upper Index Firms: Companies with Market Cap. > £10b										
Ln Market Cap	0.22 ***	0.46 ***	0.44 ***	0.39 ***	0.36 ***	0.35 ***	-0.28 ***	-0.25 ***	-0.32 ***	-0.30 ***
	(15.31)	(34.76)	(32.74)	(28.81)	(26.68)	(25.18)	(-33.39)	(-21.01)	(-19.29)	(-20.04)
Ln Price	-0.33 ***	-0.07 ***	-0.13 ***	-0.17 ***	-0.20 ***	-0.23 ***	-0.02 ***	0.04 ***	-0.07 ***	-0.05 ***
	(-27.76)	(-6.85)	(-12.28)	(-15.77)	(-18.41)	(-20.46)	(-5.73)	(6.01)	(-8.18)	(-7.04)
Ln SD	-0.53 ***	-0.63 ***	-0.60 ***	-0.59 ***	-0.58 ***	-0.57 ***	0.12 ***	0.46 ***	0.03 **	0.09 ***
	(-81.32)	(-103.52)	(-100.67)	(-98.46)	(-95.62)	(-93.25)	(21.98)	(58.27)	(2.56)	(9.59)
Ln Total Volume	0.11 ***	0.35 ***	0.29 ***	0.25 ***	0.22 ***	0.21 ***	-0.08 ***	-0.10 ***	0.13 ***	0.12 ***
	(8.67)	(29.97)	(23.91)	(20.48)	(18.12)	(16.86)	(-16.12)	(-14.32)	(13.51)	(14.25)
Proportion Dark	0.51 ***	0.60 ***	0.55 ***	0.53 ***	0.53 ***	0.52 ***	0.32 ***	0.41 ***	-0.36 ***	-0.41 ***
	(8.18)	(10.61)	(9.55)	(9.21)	(8.99)	(8.71)	(14.52)	(12.83)	(-8.16)	(-10.18)
Dark_Fragmentation	0.23 ***	0.24 ***	0.18 ***	0.14 ***	0.16 ***	0.17 ***	-0.01	0.11 ***	-0.18 ***	-0.17 ***
	(7.22)	(8.21)	(6.20)	(4.84)	(5.40)	(5.66)	(-1.22)	(6.56)	(-7.88)	(-8.16)
Lit_Fragmentation	-0.33 ***	1.15 ***	1.29 ***	1.24 ***	1.13 ***	1.04 ***	-0.50 ***	0.21 ***	-1.34 ***	-0.99 ***
	(-8.44)	(32.66)	(36.30)	(34.71)	(31.05)	(28.25)	(-38.10)	(11.21)	(-51.17)	(-41.95)
Adjusted R^2	0.247	0.397	0.370	0.343	0.323	0.308	0.372	0.485	0.505	0.437
#Observations	42024	42024	42024	42024	42024	42024	42024	42024	42024	42024
Lower Index Firms: Companies with Market Cap. < £10b										
Ln Market Cap	0.21 ***	0.56 ***	0.39 ***	0.38 ***	0.34 ***	0.31 ***	-0.09 ***	-0.15 ***	-0.04 ***	-0.08 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln Price	0.05 ***	0.20 ***	0.05 ***	0.08 ***	0.09 ***	0.10 ***	0.05 ***	0.05 ***	0.08 ***	0.08 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln SD	-0.40 ***	-0.59 ***	-0.50 ***	-0.49 ***	-0.49 ***	-0.47 ***	0.15 ***	0.32 ***	0.15 ***	0.17 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln Total Volume	0.28 ***	0.53 ***	0.40 ***	0.38 ***	0.37 ***	0.35 ***	-0.10 ***	-0.07 ***	0.12 ***	0.11 ***
	(45.45)	(77.84)	(92.38)	(94.38)	(86.41)	(80.24)	(-12.03)	(-14.33)	(-3.44)	(-7.02)
Proportion Dark	-0.42 ***	-0.99 ***	-0.76 ***	-0.75 ***	-0.69 ***	-0.64 ***	0.43 ***	0.40 ***	-0.28 ***	-0.25 ***
	(13.28)	(36.55)	(15.76)	(25.26)	(29.45)	(32.39)	(7.95)	(6.38)	(8.64)	(9.45)
Dark_Fragmentation	-0.15 ***	-0.39 ***	-0.27 ***	-0.28 ***	-0.25 ***	-0.22 ***	0.09 ***	0.31 ***	-0.30 ***	-0.23 ***
	(-93.42)	(-91.07)	(-130.08)	(-133.21)	(-134.58)	(-132.47)	(26.67)	(41.64)	(16.46)	(19.87)
Lit_Fragmentation	0.16 ***	1.68 ***	1.91 ***	1.98 ***	1.90 ***	1.78 ***	-0.64 ***	0.02	-1.17 ***	-0.83 ***
	(67.07)	(83.77)	(107.62)	(107.87)	(105.15)	(102.27)	(-20.63)	(-10.32)	(14.66)	(14.77)
Adjusted R^2	0.407	0.555	0.713	0.733	0.722	0.706	0.308	0.417	0.482	0.381
#Observations	50779	50779	50779	50779	50779	50779	50779	50779	50779	50779

Table 8 (Continued)

Panel B: Local Order Book

	LN Quoted Depth	LN Depth10	LN Depth20	LN Depth30	LN Depth40	LN Depth50	LN Quoted Spread	LN Price Impact	LN Realised Spread	LN Effective Spread
All Companies										
Ln Market Cap	0.23 ***	0.45 ***	0.42 ***	0.39 ***	0.36 ***	0.33 ***	-0.07 ***	-0.08 ***	-0.13 ***	-0.14 ***
	(64.58)	(83.54)	(82.78)	(77.84)	(75.57)	(74.63)	(-28.35)	(-14.48)	(23.32)	(23.22)
Ln Price	-0.08 ***	0.01 ***	-0.01 *	0.00	0.00	0.00	-0.01 ***	0.03 ***	-0.04 ***	-0.02 ***
	(-25.86)	(-22.62)	(-24.17)	(-22.77)	(-22.00)	(-22.21)	(19.93)	(13.10)	(-11.88)	(-12.62)
Ln SD	-0.13 ***	-0.15 ***	-0.17 ***	-0.20 ***	-0.20 ***	-0.20 ***	0.19 ***	0.37 ***	0.08 ***	0.07 ***
	(-39.59)	(-51.57)	(-59.76)	(-59.11)	(-54.69)	(-50.45)	(1.19)	(14.36)	(-14.41)	(-13.31)
Ln Total Volume	0.22 ***	0.37 ***	0.32 ***	0.29 ***	0.28 ***	0.27 ***	-0.11 ***	-0.07 ***	0.14 ***	0.13 ***
	(-94.79)	(17.72)	(53.13)	(59.25)	(54.26)	(48.30)	(-29.08)	(19.13)	(-59.58)	(-45.51)
Proportion Dark	-0.42 ***	-0.48 ***	-0.45 ***	-0.42 ***	-0.40 ***	-0.39 ***	0.37 ***	0.30 ***	-0.34 ***	-0.33 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Dark_Fragmentation	-0.33 ***	-0.57 ***	-0.57 ***	-0.56 ***	-0.51 ***	-0.46 ***	0.01	0.17 ***	-0.21 ***	-0.18 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lit_Fragmentation	-0.95 ***	0.23 ***	0.61 ***	0.67 ***	0.60 ***	0.53 ***	-0.33 ***	0.27 ***	-1.03 ***	-0.73 ***
	(0.22)	(0.28)	(0.21)	(0.20)	(0.19)	(0.19)	(1.03)	(1.01)	(1.31)	(1.37)
Adjusted R^2	0.531	0.561	0.589	0.567	0.544	0.525	0.301	0.449	0.444	0.356
#Observations	92803	92803	92803	92803	92803	92803	92803	92803	92803	92803
Upper Index Firms: Companies with Market Cap. > £10b										
Ln Market Cap	0.23 ***	0.46 ***	0.46 ***	0.42 ***	0.39 ***	0.37 ***	-0.24 ***	-0.25 ***	-0.28 ***	-0.28 ***
	(37.49)	(71.33)	(67.96)	(62.36)	(59.07)	(56.54)	(-24.40)	(-21.18)	(-17.68)	(-19.59)
Ln Price	-0.30 ***	-0.11 ***	-0.14 ***	-0.16 ***	-0.18 ***	-0.20 ***	-0.02 ***	0.04 ***	-0.08 ***	-0.07 ***
	(-60.43)	(-20.33)	(-26.23)	(-29.71)	(-33.71)	(-37.57)	(-4.58)	(7.14)	(-10.56)	(-10.32)
Ln SD	-0.07 ***	-0.05 ***	-0.08 ***	-0.10 ***	-0.10 ***	-0.10 ***	0.21 ***	0.45 ***	0.05 ***	0.03 ***
	(-27.52)	(-20.00)	(-29.00)	(-37.81)	(-40.20)	(-40.31)	(32.19)	(57.07)	(4.36)	(2.86)
Ln Total Volume	0.18 ***	0.33 ***	0.28 ***	0.25 ***	0.24 ***	0.22 ***	-0.12 ***	-0.10 ***	0.12 ***	0.12 ***
	(33.42)	(57.30)	(47.30)	(42.48)	(39.67)	(37.96)	(-21.24)	(-14.20)	(13.33)	(14.20)
Proportion Dark	-0.40 ***	-0.19 ***	-0.20 ***	-0.14 ***	-0.13 ***	-0.16 ***	0.44 ***	0.46 ***	-0.40 ***	-0.45 ***
	(-15.26)	(-6.94)	(-6.76)	(-4.88)	(-4.58)	(-5.58)	(16.72)	(14.21)	(-9.46)	(-11.67)
Dark_Fragmentation	-0.42 ***	-0.55 ***	-0.62 ***	-0.62 ***	-0.58 ***	-0.54 ***	-0.06 ***	0.07 ***	-0.21 ***	-0.20 ***
	(-31.70)	(-39.10)	(-42.20)	(-42.44)	(-39.65)	(-37.69)	(-4.26)	(4.54)	(-9.61)	(-10.13)
Lit_Fragmentation	-1.08 ***	0.17 ***	0.46 ***	0.42 ***	0.33 ***	0.26 ***	-0.37 ***	0.28 ***	-1.09 ***	-0.79 ***
	(-65.87)	(9.94)	(25.40)	(23.76)	(18.61)	(14.98)	(-24.06)	(14.52)	(-43.84)	(-35.23)
Adjusted R^2	0.223	0.476	0.424	0.392	0.371	0.356	0.305	0.490	0.461	0.407
#Observations	42024	42024	42024	42024	42024	42024	42024	42024	42024	42024
Lower Index Firms: Companies with Market Cap. < £10b										
Ln Market Cap	0.21 ***	0.48 ***	0.44 ***	0.43 ***	0.39 ***	0.36 ***	-0.13 ***	-0.19 ***	-0.08 ***	-0.11 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln Price	0.04 ***	0.10 ***	0.07 ***	0.09 ***	0.10 ***	0.11 ***	0.02 ***	0.02 **	0.06 ***	0.09 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln SD	-0.37 ***	-0.61 ***	-0.56 ***	-0.57 ***	-0.56 ***	-0.54 ***	0.16 ***	0.27 ***	0.13 ***	0.12 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln Total Volume	0.25 ***	0.45 ***	0.38 ***	0.36 ***	0.35 ***	0.34 ***	-0.12 ***	-0.06 ***	0.14 ***	0.13 ***
	(50.99)	(72.84)	(88.94)	(90.50)	(84.52)	(79.86)	(-16.03)	(-18.53)	(-6.91)	(-9.29)
Proportion Dark	-0.35 ***	-0.73 ***	-0.61 ***	-0.59 ***	-0.54 ***	-0.50 ***	0.42 ***	0.39 ***	-0.38 ***	-0.33 ***
	(13.29)	(19.04)	(17.97)	(25.84)	(29.73)	(33.08)	(3.24)	(2.07)	(6.87)	(10.24)
Dark_Fragmentation	-0.17 ***	-0.32 ***	-0.33 ***	-0.33 ***	-0.29 ***	-0.25 ***	0.09 ***	0.35 ***	-0.32 ***	-0.28 ***
	(-96.77)	(-101.99)	(-125.22)	(-129.27)	(-132.80)	(-133.10)	(26.79)	(37.19)	(14.60)	(14.28)
Lit_Fragmentation	-0.96 ***	0.15 ***	0.58 ***	0.71 ***	0.67 ***	0.60 ***	-0.35 ***	0.12 ***	-0.92 ***	-0.61 ***
	(66.43)	(77.23)	(86.61)	(85.41)	(85.04)	(85.18)	(-22.76)	(-10.09)	(18.84)	(17.47)
Adjusted R^2	0.445	0.507	0.601	0.613	0.608	0.600	0.253	0.445	0.461	0.348
#Observations	50779	50779	50779	50779	50779	50779	50779	50779	50779	50779

A visual representation of the above effect on depth can be seen in Figures 10 and 11**.** In Figure 10**,** we can see that after the introduction of MiFID and the resulting fragmentation beginning on November 1 2007, depth deeper in the order book reaches levels higher than those prior to the introduction of MiFID, while depth at the quoted level remains fairly constant. On the contrary, Figure 11 shows that after the introduction of MiFID local order book depth at the best price level was not able to recover to the levels it reached previously.

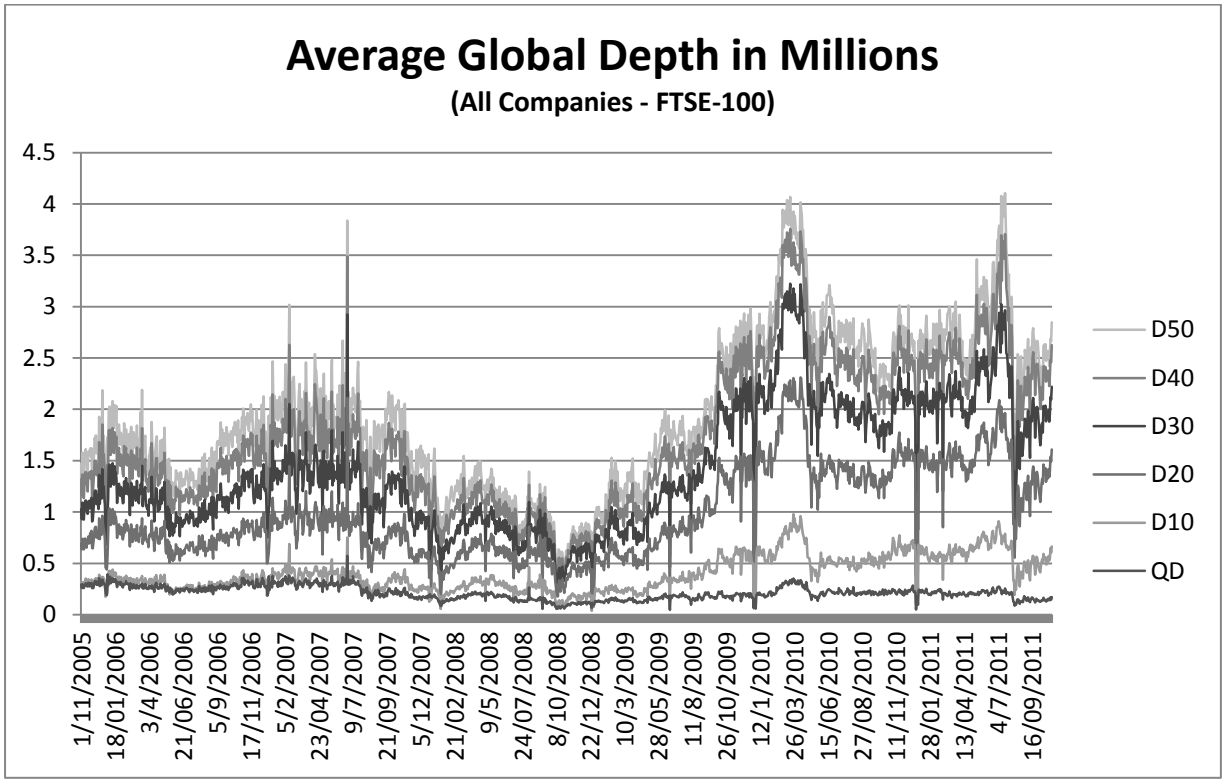


Figure (10) Average Global Depth for all FTSE-100 stocks

The figure shows the daily average depth(£) at various levels for all FTSE-100 stocks in the study for the consolidated global order book. We begin with quoted at the best price level and move to depth at various distances away from the midpoint of the best bid-ask spread. The legend displays labels for lines in the order in which they appear in the graph, with quoted depth being the lowest line and depth at 50 basis points above and below the midpoints of the quoted depth at the top.

We propose that improved liquidity in the global order book is due to the effects of increased competition in the lit order book market. New exchanges have attracted liquidity, by offering reductions in transaction costs for those supplying liquidity to the market. This results in the migration of market makers to the newly formed regulated markets where they can offer better prices, in the form of tighter spreads, due to the cost savings offered to them by the exchange for supplying liquidity. Our findings on spreads and transaction costs support the findings by Degryse, de Jong, and van Kervel (2011) and Gresse (2012) who argue that the local exchange adapts and offers a reduction in spreads in order to remain competitive. As a result, and in accordance with the aforementioned studies, we find that visible order book fragmentation improves the market for retail and institutional investors alike in terms of pricing and transaction costs.

In summary, we conclude that market quality improves as a result of increased lit order book fragmentation. However, retail investors will not experience benefits to the same extent as institutional investors.

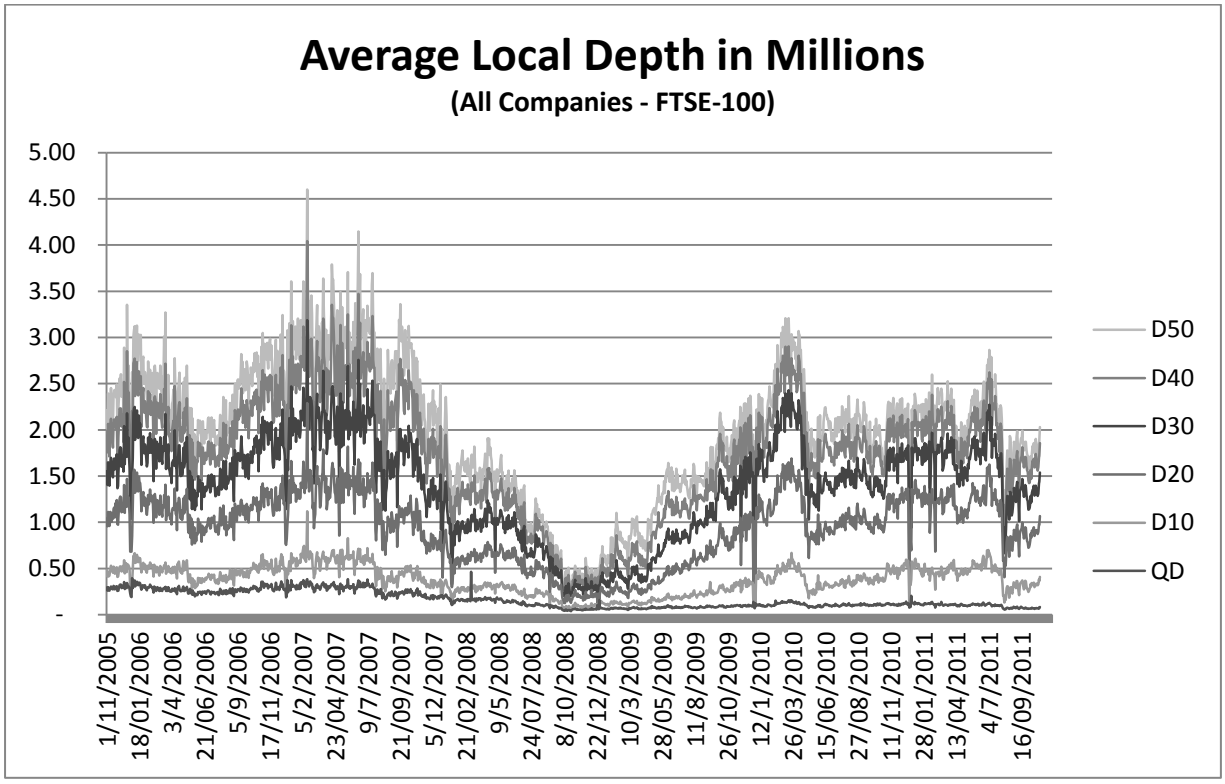


Figure (11) Average Local Depth for all FTSE-100 stocks

The figure shows the daily average depth(£) at various levels for all FTSE-100 stocks in the study for the local order book of the primary exchange (London Stock Exchange). We begin with quoted at the best price level and move to depth at various distances away from the midpoint of the best bid-ask spread. The legend displays labels for lines in the order in which they appear in the graph, with quoted depth being the lowest line and depth at 50 basis points above and below the midpoints of the quoted depth at the top.

9.2 Dark Market Share

In this section we present our findings regarding the market quality implications of an increased market share for dark liquidity. Increases in the market share of dark liquidity (Proportion_Dark) imply a migration of orders from lit to dark exchanges. We continue to refer to Panels A and B of Table 8 when discussing global and local order book results, respectively. In existing studies, dark market share is the measure used to represent dark fragmentation. Please note that all coefficients in this section are significant at the 1% level. For findings regarding the effects of actual dark order book fragmentation, as opposed to dark order book market share, please refer to the following section, Section 9.3.

In Table 8 Panel A, we observe that the global quoted spreads widen by 35% when the market moves from using no dark liquidity to only dark liquidity. Upper and lower firms experience a widening of spreads to the extent of 32% and 43%, respectively. In Table 8 Panel B we observe that local quoted spreads widen by 37% with upper and lower firms' spreads widening by 44% and 42%,

respectively, when the market moves from using no dark liquidity to only dark liquidity. In other words, when fragmentation increases by 0.01, or 1%, as measured by 1-HHI , global and local quoted spreads widen by 0.35% and 0.37% respectively.

Global spread results support our second hypothesis that trades for lower market capitalisation firms, who are less liquid, are more informative and their resulting impact on spreads is greater than the migration of less informative upper index share trades.

Our findings partly contradict the theoretical predictions and empirical results made by Buti, Rindi, and Werner (2010) and (2011), respectively, as well as the findings by O'Hara and Ye (2011). They argue that global market quality improves while local market quality worsens as orders migrate from lit to dark. We argue that increased migration, represented by a higher dark order book market share, has a negative effect on both global and local order books.

Our findings partly contradict the theoretical predictions and empirical results made by Buti, Rindi, and Werner (2010) and (2011), respectively, as well as the findings by O'Hara and Ye (2011). They argue that global market quality improves while local market quality worsens as orders migrate from lit to dark. We argue that increased migration, represented by a higher dark order book market share, has a negative effect on both global and local order books.

Globally and locally, any use of dark liquidity has a negative effect on price efficiency as indicated by price impact coefficients of 0.3 and 0.31 respectively. This implies that moving from a market that uses no dark liquidity to one that uses dark liquidity exclusively increases the price impact of a trade by roughly 30%.

Our results regarding price efficiency support the empirical findings of Weaver (2011), Nimalendran and Ray (2011), and Forde and Putnins (2012). The findings of the aforementioned studies support our second hypothesis in that the increase in price impact and the widening of quoted spreads results from greater information asymmetry caused by the migration of informative trades from the lit to the dark order book. Our results regarding price efficiency also support the findings of Zhu (2012) who argues the results are consistent with the concept of cream-skimming. However, while we agree with Weaver (2011) and Degryse, de Jong, and van Kervel (2011) who conclude that overall market quality is reduced when faced with increased dark liquidity trading, we disagree with the idea that global liquidity is improved at the expense of local liquidity. We argue that both global and local liquidity is made worse off by the increased migrations of orders to the dark order book.

As trades migrate from the lit order book to the dark order book, the resulting effects on depth are negative. Global and local quoted depths decrease by 0.08% and 0.42% for every increase in dark market share of 1%. As we move slightly deeper into the order book, 10 basis points from the

midpoint of the best bid/ask price, we find that global and local depth decreases by 0.34% and 0.48% for every increase in dark market share of 1%. This is expected as we mention previously in this section that the migration of informed orders to the dark market reduces investor confidence in advertised prices. This results in more investors moving away from posting quotes near the best price level as they are no longer confident in the price and prefer to protect their positions by offering less competitive prices.

In summary, we find that market quality suffers as trades migrate from lit to dark order book markets due to increased information asymmetry resulting from the loss of informed trades in the visible order book.

9.3 Dark Fragmentation

In this section we focus on the effect of dark order book fragmentation on market quality. As we are the first study to explicitly measure dark order book fragmentation, and all previous empirical and theoretical papers focus on order flow migration as in Section 9.2, we do not have any previous studies to which we can directly compare our results.

We find that, contrary to our hypothesis, increased fragmentation in the dark order book results in wider spreads in the global order book, with a coefficient of 0.04, while the effect on the local order book is insignificant. This implies that when we move from a perfectly consolidated to a perfectly fragmented dark order book market, global spreads only widen by 4%. This effect is quite small, implying that the effects of dark order book fragmentation are not nearly as influential on market quality as order migration to the dark order book and lit market fragmentation. Again, unless otherwise stated, each coefficient in this section has been found to be significant at the 1% level.

However, the sign for the coefficient is positive which is not expected. Upon further inspection of our independent variables we notice that the correlation between dark fragmentation and dark market share is 0.53 and the correlation between dark fragmentation and dark volume 0.49. Hypothesis 3 revolves around the assumption that increased fragmentation in dark order books leads to a decrease in dark volume and market share due to a decreased probability of execution resulting from the dispersion of orders across multiple exchanges. In contrast, our correlation coefficients indicate that dark markets are more popular when order books are fragmented, not less popular. We first consider whether this could be due to inaccuracy in the dark fragmentation measure prior to the introduction of MiFID, as we mention in Section 7.6 that many dark trades went unreported prior to the introduction of MiFID, hence the large spike in dark trading immediately on November 1 2007. To check whether the pre-MiFID data is heavily influencing our results, we inspect the correlation between the pairs of variables during the post MiFID period. We

find no major deviations from the previous pattern and observe a correlation between dark fragmentation and dark volume of 0.359 and dark fragmentation and dark market share of 0.301.

The relationship between dark order book fragmentation, dark market share, dark volume and probability of execution must be studied further in order to understand why fragmented dark markets can support more trades. We argue that this is partially due to our understanding of dark trading prior its increase in popularity. When dark markets were in their infancy and supported few customers it is likely that it was difficult to find an opposing party to the trade. However, since the introduction of MiFID dark markets have increased in popularity and now consist of 29.4% of total trading volume versus 8% back in pre-MiFID times, as indicated in Table 2. This supports the idea that a fragmented dark order book today can support customers to the same extent as a consolidated dark order book prior to the introduction of MiFID and that the number of dark pools can fluctuate in order to serve a growing client base. If we expand this concept to several dark order book markets what we are left with are multiple dark order books who, individually, can maintain a reasonable probability of execution and support trade execution due to the increase in orders. In this case, fragmentation, to some extent, can benefit dark pool transactions as investors can break up large orders and not only hide them within a single dark pool, but across multiple dark pools. Spreading a large order across multiple venues provides greater trade anonymity since it is more difficult to detect large orders spread across multiple venues than across a single venue.

This form of self-regulation is likely behind the phenomenon that while the number of unconsolidated dark trading venues has increased over the study period, as indicated in Figure 2, the number of consolidated trading venues has remained fairly constant. This indicates that while dark trading form in order to serve a growing client base, there is a limit to the number of dark order books that can operate successfully. Dark trading venues will form liquidity partnerships as necessary in order to maintain a reasonable probability of execution in order to meet the needs of their clients.

If we take into consideration our adjusted assumption that increased fragmentation is correlated with increased migration to dark markets, it follows that spreads should widen and price impact should increase as indicated in Section 9.2. The results are driven by the concept of informative trades leaving the lit order book market and moving to the dark, leaving behind investors whose confidence in quoted prices decreases. The result is a widening of global spreads by 0.04% for every increase in dark order book fragmentation of 0.01, or 1%, which supports our third hypothesis.

In summary, dark order book fragmentation harms market quality by widening spreads, however the extent of the impact is minimal.

10.0 Conclusion

Over half of the USA's residents report that they own a stock directly or through investment vehicles and, according to Mary Jo White of the Consumer Federation of America, this is representative of all developed economies. This implies that the majority of households are directly connected to the securities market. Therefore, comprehensive regulatory policies may need to be adapted in order maintain investor confidence and support our financial markets.

The dark order book market has significantly fragmented since the introduction of MiFID. However, if implicit consolidation of order books is considered, the market is only slightly more fragmented than its visible liquidity counterpart, as presented in Figure 4. In fact, dark markets are able to self-regulate the number of distinct order books that are offer dark liquidity. This is observed in the consolidated measure in Figure 2 which indicates that regulation regarding the number of dark trading venues in operation is unwarranted and that these policies should not be enacted.

Lit order book fragmentation has a largely positive effect on overall market quality in the form of tighter quoted spreads and lower realised and effective spreads resulting from increased market competition for liquidity. However, effects are greater in the consolidated global order book compared to the primary exchange, as represented by the London Stock Exchange, implying that institutional investors are able to realise greater benefits than retail investors.

Increased dark order book activity in the form of order migration from the lit to the dark market has a negative overall effect on both global and local order books. Dark trades are found to contain information and, as these trades migrate to the dark market, greater information asymmetry among investors leads to a reduction in market quality in the form of wider spreads and greater price impact.

Dark order book fragmentation has a negative impact on market quality in the form of wider spreads and greater price impact. However, the effects are more than overshadowed by the effect of lit order book fragmentation and order migration to dark order books.

Our research supports the discussion surrounding the market quality implications of increased activity in the dark order book market and provides policymakers with the necessary information to make informed decisions regarding the policies that govern the financial market. We argue that regulators can largely ignore dark order book fragmentation but must pay special attention to the migration of orders to the dark market. If dark liquidity is too widely available and its use encouraged, leading to a rise in dark order market share, the effect will be negative across all individual exchanges and across the market as a whole. However, competition for visible liquidity should be encouraged.

11.0 Discussion

The creation of a distinct measure of dark order market fragmentation can be applied to price discovery and adverse selection studies. The concept of consolidated liquidity can also be extended to lit exchanges. With the advent of SORT in lit trading venues as well as their dark counterparts, participants can automatically send their orders to multiple trading venues. Therefore it will be beneficial to identify the implicit consolidation events in the lit markets and, in combination with those of the dark order market, study their effects on market quality.

The main limitation of the study is the accuracy of the dark fragmentation measure. As mentioned in the introduction, 49% of dark trading activity cannot be assigned to a particular trading venue. As a result, we have to evenly weigh the output across all trading venues who report to the trade reporting facility Markit BOAT. An accurate proxy could not be found due to inconsistencies in trade reporting.

Another limitation is the accuracy of the consolidation measures as reported by the fragmentation and consolidation timeline. The timeline organises fragmentation and consolidation events in the dark order book market by categorizing the press releases from and articles pertaining to various dark order book operators. However, there exist some gaps in the timeline. As the contents of Markit BOAT's consolidated tape must be attributed to a series of dark liquidity venues it is important to know exactly how many venues are reporting to Markit BOAT at any given time. Unfortunately, Markit BOAT's press releases are not as frequent as those by some liquidity providers. This results in gaps in the data. For example, on June 29 2010 Markit BOAT issued a press release regarding the inclusion of Instinet BlockMatch trades to the consolidated tape and included the names of several reporting venues for whom an explicit announcement was not made. The result was a significant spike in the number of trading venues as indicated in Figure 2. This is a limitation to the measure and results from imperfect reporting by the trading venues or trade reporting firms.

This will result in small periods where the fragmentation is either slightly over or under reported. We do not, however, feel that this will cause any significant error in our findings as the difference in the HHI when dark trading is spread across 30 versus 35 indistinguishable venues, for example, is minimal. Due to the nature of the fragmentation measure we find that even when our count of pooled transaction reporting venues is adjusted up or down by up to eight companies the overall effect is minimal.

In future versions of this study we will include the results originating from an instrumental variables regression. This will help take into consideration the fact that relationships between the regressors and the dependent variables are not necessarily uni-directional. We can also take into consideration

that fragmentation, both dark and lit, may only be beneficial or harmful to a certain extent and that an ideal level of fragmentation may exist in the those markets.

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Appendix A: Supplementary Dataset Information

This section contains various data pertaining to the dataset used for the study.

Table (A1) Stock Selection

The following table contains information regarding the reasons for a FTSE-100 constituent's exclusion from our study. We began with 102 stocks; greater than 100 as some stocks were late additions to the index and only recently replaced members who should be included in the study. Of those 102 index constituents 28 were excluded for not maintaining continuous membership in the index throughout the study period while 20 members were excluded for falling into the category of 'Financial' stocks (Excluded stock do not contain a size indicator value for Large). The result was a total of 53 stocks included in the study representing 52 companies; Royal Dutch Shell has both class A and B stocks listed as part of the FTSE-100 index. The remaining 53 stocks are classified as upper index stocks (Large = 1) if their average market cap throughout the study period exceeded £10b. The size classification resulted 24 'under index/ stocks and 29 'lower index' stocks.

FTSE 100 Constituents	Date Added to Index	Used in Study (1 = Yes, 0 = No)	Reason For Exclusion	Notes	Replaced The Following Index Members	Large
A.b.food (ABF)	18-Dec-00	1				0
Abdn.asset.man. (ADN)	7-Mar-12	0	Fund Management			
Admiral Grp (ADM)	24-Dec-07	0	Insurance			
Aggreko (AGK)	1-Dec-09	0	Late Addition to Index			
Amec (AMEC)	20-Dec-07	0	Late Addition to Index			
Anglo American (AAL)	21-Jun-99	1				1
Antofagasta (ANTO)	8-Mar-04	1				0
Arm Hldgs. (ARM)	20-Dec-99	1				0
Astrazeneca (AZN)	6-May-99	1				1
Aviva (AV.)		0	Insurance	Originally CGNU		
Babcock Intl (BAB)	12-Jun-12	0	Late Addition to Index		Man Group (Entered Sep 2001)	
Bae Sys. (BA.)	24-Jun-05	1				0
Barclays (BARC)		0	Banking			
Bg Grp. (BG.)	24-Jun-05	1				1
Bhp Billiton (BLT)	22-Sep-97	1		Originally Billiton		1
Bp (BP.)	24-Jun-05	1				1
Br.amer.tob. (BATS)	8-Sep-99	1				1
Br.land (BLND)		0	Property			
Bskyb (BSY)	19-Sep-95	1				0
Bt Group (BT.A)	19-Nov-01	1				1
Bunzl (BNZL)	30-Apr-08	0	Late Addition to Index			
Burberry Grp (BRBY)	1-Sep-09	0	Late Addition to Index			
Cairn Energy (CNE)	Pre-2007	1				1
Capita Group (CPI)	18-Jun-04	1				0
Carnival (CCL)	24-Dec-01	1		Originally P&O Cruiselines		1
Centrica (CNA)	14-Feb-97	1				0
Cocacola Hbc Ag (CCH)	11-Sep-13	0	Late Addition to Index		Serco(Entered 22 Dec 2008 - Late Addition to Index) Eurasian Natural Resource Corp (Entered 26 March 2008 - Late Addition to Index) Wood Group(Multiple Entries)	
Compass Group (CPG)	2-Feb-01	1				0
Crh (CRH)	7-Dec-11	0	Late Addition to Index		Inmarsat(Entered 22 Sept 2008)	
Croda Intl. (CRDA)	7-Mar-12	0	Late Addition to Index		Cairn Energy (Entered 17 Sept 2004)	
Diageo (DGE)	17-Dec-97	1				1
Easyjet (EZJ)	6-Mar-13	0	Late Addition to Index		Intu Properties (Financial Company)	
Experian (EXPN)	11-Oct-06	1				0
Fresnillo (FRES)	22/09/2008 & 11/03/2009	0	Multiple Entries into Index			
G4s (GFS)	24-Dec-07	0	Late Addition to Index			
Gkn (GKN)	29-May-02	1				0
Glaxosmithkline (GSK)	27-Dec-00	1				1
Glencore Xstra (GLEN)	25-May-11	0	Late Addition to Index		Invensys (Entered 23 June 2008 - Late Addition to Index)	
Hammerson (HMSO)	17-Jun-05	0	Property			

Table (A1) (continued)

FTSE 100 Constituents	Date Added to Index	Used in Study (1 = Yes, 0 = No)	Reason For Exclusion	Notes	Replaced The Following Index Members	Large
Hargreaves Lans (HL.)		0	Finance			
Hsbc Hldgs.uk (HSBA)		0	Banking			
Imi (IMI)	8-Dec-10	0	Late Addition to Index			
Imp.tobacco Grp (IMT)	27-Jul-00	1				1
Intercon. Hotel (IHG)	25-Jun-05	1				0
Intertek Group (ITRK)	11-Mar-09	0	Late Addition to Index			
Intl Consol Air (IAG)	24-Jan-11	0	Late Addition to Index			
Itv (ITV)	9-Mar-11	0	Late Addition to Index	Previously left index September 2008		
Johnson Matthey (JMAT)	24-Jun-02	1				0
Kazakhmys (KAZ)	Pre-2007	1				0
Kingfisher (KGF)	Pre-2007	1				0
Land Secs. (LAND)		0	Property			
Legal&gen. (LGEN)		0	Insurance			
Lloyds Grp. (LLOY)		0	Banking			
Man Group (EMG)	24-Sep-01	0	Investment			
Meggitt (MGGT)	1-Oct-11	0	Late Addition to Index		Autonomy Corp (Entered 22 Sept 2008 + multiple other dates)	
Melrose Ind (MRO)		0	Finance			
Mondi (MNDI)	10-Sep-13	0	Late Addition to Index	Entered with Coca-Cola (No suitable predecessors)		
Morrison (Wm) (MRW)	10-Apr-01	1				0
National Grid (NG.)	11-Dec-95	1				1
Next (NXT)	18-Jun-01	1				0
Old Mutual (OML)		0	Insurance			
Pearson (PSON)	Original Member	1				1
Persimmon (PSN)		0	Early Exit from Index	Exited March 2008		
Petrofac (PFC)	23-Jun-08	0	Mutliple Entries into Index			
Prudential (PRU)		0	Finance			
Randgold Res. (RRS)	22-Dec-08	0	Late Addition to Index			
Rds 'A' (RDSA)	15-Jul-05	1		Royal Dutch Shell A and B		1
Rds 'B' (RDSB)	15-Jul-05	1				1
Reckitt Ben. Gp (RB.)	Original Member	1				1
Reed Elsevier (REL)	Original Member	1				1
Resolution (RSL)		0	Investment			
Rexam (REX)	Original Member and 23-Sept-2002	1				0
Rio Tinto (RIO)	Original Member	1				1
Rolls-royce Hlg (RR.)	11-Jun-03	1				0
Royal Bank Scot (RBS)		0	Banking			
Rsa Ins. (RSA)		0	Insurance			
Sabmiller (SAB)	22-Mar-99	1		Originally South African Breweries		1
Sage Grp. (SGE)	20-Sep-99	1				0
Sainsbury(j) (SBRY)	Original Member	1				0
Schroders (SDR)		0	Non-continous Membership	Left Index from 15 March 2006 to 30 March 2007		
Severn Trent (SVT)	24-Sep-01	1				0
Shire (SHP)	26-Oct-00	1				0
Smith&nephew (SN.)	12-Jul-01	1				0
Smiths Group (SMIN)	18-Dec-00	1				0
Sportsdirect (SPD)	5-Jul-05	0	Late Addition to Index	Entered with Coca-Cola (No suitable predecessors)		
Sse (SSE)	16-Dec-98	1				1
Stand.chart. (STAN)		0	Banking			
Std Life (SL.)		0	Fund Management			
Tate & Lyle (TATE)	17 Dec 04 and 6 March 08 and 22 Dec 08 and 08 June 11	0	Mutliple Entries into Index			
Tesco (TSCO)	Original Member	1				1
Travis Perkins (TPK)	13-Jun-13	0	Late Addition to Index		Evraz (Entered 07 Dec 2011 - Late Addition to Index) Evraz Replaced Investec (Entered 10 March 2010 - Late Addition to Index) Investec Replaced Resolution (Entered 15 March 2006 - Early Exit from Index) Polymetal International (Entered 07 Dec 2011 - Late Additin to Index) Polymetal Replaced Lonmin (Entered 07 June 2007 - Early Exit from Index)	
Tui Travel (TT.)	24 Dec 2007 and 10 Dec 2012	0	Multiple Entries into Index			
Tullow Oil (TLW)	24-Sep-07	0	Late Addition to Index			
Unilever (ULVR)	Original Member	1				1
Utd. Utilities (UU.)	2-Apr-90	1		Originally Northwest Water		0
Vedanta (VED)	7-Jun-06	1				0
Vodafone Grp. (VOD)	Pre 2007	1				1
Weir Grp. (WEIR)	8-Sep-10	0	Early Exit from Index		Replaced by Segro (Exited in 2007 and Entered in 2009)	
Whitbread (WTB)	15-Dec-06	1				0
William Hill (WMH)	In and out (back in 2013)	0	Multiple Entries into Index		Replaced by Kazakhmys	
Wolseley (WOS)	24-Sep-01	1				0
Wpp (WPP)	22-Jun-98	1				0

Table (A2) Transaction Indicators

This table contains information on the trade qualifiers used to identify important transactions. Some qualifiers indicate dark transactions that do not originate from an exclusively dark liquidity provider. In some cases this is also indicated by a suffix to the firm's RIC. Other qualifiers indicate transactions that should be ignored.

Qualifier/RIC Suffix	Value	Exchange Affected	Description
R	v	All	Dark Transaction
R	p	All	Dark Transaction
Q	4	All	Cancel Transaction
Q	RCK	All	Cancel Transaction
Q	XSMP	All	Dark Transaction (Smarpool)
Q	OFF	VX	Dark Transaction (Off Exchange)
Q	U	All	Uncrossing (Ignore)
Q	N	All	Dark Transaction (Negotiated)
Q	T	L	Dark Transaction
Q	R	All (Except L)	Dark Transaction
Q	K	All	Dark Tranaction
Q	H	All	Dark Transaction (Hidden)
Q	X	All	Dark Transaction (Crossed)
Q	S	All	Dark Transaction (Systematic Internalizer)
Q	W	All	Dark Transaction (VWAP)
Q	P	All	Dark Transaction (Protected Portfolio)

Table (A3) Fragmentation and Consolidation Event Timeline

The timeline of fragmentation and consolidation events is built by categorizing the news events and press releases of the various dark liquidity providers and trade reporting facilities. The table contains a list of fragmenting and consolidating events and information on other events of interest (e.g. Notification of a company reporting trades to Markit BOAT). Identifiers used to classify the events can be found in the Subject and Event Code legend located below. By organizing the news events in chronological order we construct a timeline that we use to keep track of how many distinct dark pools are in existence, how many firms are reporting to the consolidated tape and how many consolidated venues have formed as a result of liquidity sharing.

LEGEND

Subject		**Event Code**	
D	Dark Order Book	O	Opened/Created
L	Lit Order Book Market	C	Closed
B	Broker Crossing Network (BCN)	MS	Modified Services
S	Systematic Internalizer	MSE	Modified Services (Additional Equities Offerings)
R	Regulated Market	MSA	Modified Services (Aggregation)
AL	Aggregator Algorithm Lit (Smart Order Routing - SOR)	MC	Modified Company
AD	Aggregator Algorithm Dark (SOR)		
ALD	Aggregator Algorithm Lit and Dark (SOR)		
DL	Dark and Lit		
OTC	Over the counter		

Table (A3) (continued)

Date	Subject	Event Code	Description	Link1
2/5/2007	D	MS	ITG launches POSIT NOW, continuous crossing in Europe. Regular Posit is Posit Match (Exact date in Notes link)	http://investor.itg.com/phoenix.zhtml?c=100516&p=irol-newsArticle&ID=958312&highlight=
3/30/2007	AL	MSA	CA Cheuvreux SOR algos have access to Chi-x	https://www.cheuvreux.com/pdf/PR%2023%20december%202008%20CA%20Cheuvreux%20Nasdaq%20OMX.pdf
10/24/2007	OTC	MS	ITG Expands cross borders trading between US, Canada and Europe in Triton	http://investor.itg.com/phoenix.zhtml?c=100516&p=irol-newsArticle&ID=1066490&highlight=
11/1/2007	-	O	BOAT Launches with ABN Amro, Citigroup, Credit Suisse, Deutsche Bank, Goldman Sachs, HSBC, Merrill Lynch, Morgan Stanley and UBS	http://www.finextra.com/news/fullstory.aspx?newsitemid=17344
11/1/2007	D	O	BlockMatch is registered as an MTF	http://www.mondovisione.com/media-and-resources/news/instinet-blockmatch-granted-approval-to-reference-european-consolidated-price/
11/13/2007	AD	O	ITG adds 'Active' to its European suite of algorithms. Access Posit dark liquidity pool. (Notes for exact date)	http://investor.itg.com/phoenix.zhtml?c=100516&p=irol-newsArticle&ID=1076264&highlight=
3/17/2008	D	O	NYFIX launches Euro Millium European dark pool with UK stocks for now and more coming soon. See link for list of major investment firms.	http://www.prnewswire.com/news-releases/nyfix-launches-euro-millennium-dark-pool-56935587.html
5/2/2008	D	I	Liquidnet begins reporting to Markit BOAT	http://www.markit.com/en/media-centre/press-releases/detail.page?dcr=/markit/PressRelease/data/2008/05/2008-05-02-2
7/28/2008	D	MSA	Instinet BlockMatch and CS CrossFinder share access to dark pools	http://www.instinet.com/includes/pdf/news/IEL_CS_Partnership_.pdf
8/14/2008	OTC	MSA	Instinet Europe begins trading on Turquoise (Instinet clients have access to trading on Turquoise book)	http://www.nomuraholdings.com/news/nr/europe/20080723/20080723.pdf
8/14/2008	D	MSA	Instinet Blockmatch clients can access Turquoise dark order types	http://www.nomuraholdings.com/news/nr/europe/20080723/20080723.pdf
9/16/2008	AD	O	ITG launches ITG Dark algo in Europe (Exact date in Link2)	http://investor.itg.com/phoenix.zhtml?c=100516&p=irol-newsArticle&ID=1197632&highlight=
2/2/2009	D	O	Smartpool launches with partnership from NYSE Euronext, BNP Paribas, HSBC and JP Morgan. Markets phased in but 15 total by Feb 23rd. Start with Germany, Austria, Netherlands, Belgium (Smartpool info page on Thomson Reuters -Speed Guide)	http://www.tradeonsmartpool.com/Assets/Documents/PressFSAApproval.pdf?1244644460
2/2/2009	D	MSA	Instinet to begin trading on Smartpool	http://www.nomuraholdings.com/news/nr/europe/20090202/20090202.pdf
5/7/2009	D	O	Nasdaq IMX Europe announces launch of NeuroDark. Trading in top 800 European Shares (Same as Nasdaq OMX Europe itself)	http://www.nasdaqomx.com/newsroom/pressreleases/pressrelease/?messageId=538539&displayLanguage=en
5/26/2009	D	O	Chi-x Europe goes live with Chi-Delta Non-displayed order book	http://www.nomuraholdings.com/news/nr/europe/20090526/20090526.pdf
7/1/2009	AD	O	Turquoise launched TQ Lens with liquidity partners: CA Cheavreax, Citadel Securities, Citi, Deutsche Bank, Merrill Lynch International, and Nomura	http://www.thetradenews.com/print.aspx?id=2920
7/13/2009	D	MSA	Leading investment firms join smartpool. Look for list in link	http://www.tradeonsmartpool.com/Assets/Documents/PressReleaseSmartPoolnames130709.pdf?1247472289
8/7/2009	D	O	Bats-Europe launches dark pool	http://www.informationweek.com/bats-europe-dark-pool-launch-set/218500874
8/19/2009	AD	MSA	Instinet Europe becomes latest firms to join TQ Lens	http://www.tradeturquoise.com/press/instinet_europe_joins_tq_lens.pdf
10/8/2009	D	MSA	Bats Europe providing Nomura clients with direct access to Bats Europe platform	http://cdn.batstrading.com/resources/press_releases/BATSEurope_Nomura_SponsoredAccess_FINAL.pdf
11/10/2009	D	MSA	Smartpool adds BoA Merril Lynch and CA Cheuvreux to dark pool community. Linking of lit order books and dark pools	http://www.tradeonsmartpool.com/Assets/Documents/091110_SmartPoolNewCustomers.pdf?1257851044
11/11/2009	S	O	Knight launches Knight link in Europe	http://www.informationweek.com/knight-launches-knight-link-in-europe/221601217
11/16/2009	AD	MSA	CA Crossfire algo provides access to new dark pools.	https://www.cheuvreux.com/pdf/PR%2016%20november%202009%20New%20Dark%20Pools.pdf
11/30/2009	D	C/Aggregation	NYSE Technologies shuts down Euro Millenium dark pool following take over. Smartpool will take all Euro Millenium clients (Link2)	http://www.finextra.com/news/fullstory.aspx?newsitemid=20811
12/2/2009	D	MS/ MSE	Six Swiss Exchange partners with Smartpool to deliver Swiss Block, MYFIX Euro Millenium dropped	http://www.tradeonsmartpool.com/Assets/Documents/SmartPoolSwissBlock21209.pdf?1259857221
1/25/2010	D	O	Nomura goes live with NX MTF, the first principal broker dealer established MTF dark pool. Began trading in stocks across 14 european markets	http://www.nomura.com/europe/resources/upload/NX_go_live_-_01_February_2010.pdf
5/21/2010	D	C	Nasdaq OMX Europe closes Neuro. Double check but Neuro dark should be closing too	http://www.nasdaqomx.com/newsroom/pressreleases/pressrelease/?messageId=943974&displayLanguage=en
6/29/2010	D	I	Instinet's BlockMatch will report all trades to Markit BOAT	http://www.mondovisione.com/media-and-resources/news/instinet-blockmatch-report-their-trades-using-markit-boat/
11/1/2010	OTC	MSA	Instinet connects to equiduct systems hybrid book	http://www.nomuraholdings.com/news/nr/europe/20101101/20101101.pdf
11/9/2010	D	O	UBS goes live with dark MTF called UBS MTF	http://www.efinancialnews.com/story/2010-11-09/ubs-mtf-goes-live
1/18/2012	D	MC	Pipeline changes name to Aritas Securities	http://www.advancedtrading.com/crossingnetworks/following-scandal-pipeline-switches-name/232500047
3/28/2011	D	O	Goldman sachs launches Sigma X	http://www.theaustralian.com.au/business/wall-street-journal/goldman-plunges-into-dark-pools/story-fnay3vxj-1226297838503
4/16/2012	D	O	CA Cheuvreuz launches pan-Europen dark book, Blink MTF. See link for securities coverage	http://www.credit-agricole.com/en/News/Press-releases/General-Press-Releases/CA-Cheuvreux-launches-its-own-pan-European-MTF-BLINK